

# Tricolor Emission Line Imaging

By Richard Crisp

## The Inspiration: Hubble Pillars of Creation image

When the Hubble image of the Eagle Nebula “Pillars of Creation” was published a few years ago, I was impressed by the amazing detail and beauty of that image, it was unlike anything I had ever seen. Part of the appeal to me was the unusual color of the image arising from the use of narrowband emission line filters. Once I began taking tricolor narrowband emission line images, it wasn't long before I attempted the Pillars target. I was able to capture the image in the summer of 2003. Shortly after publishing the image, Mike Cook (AF9Y) combined my [SII], Halpha and [OIII] color data with Stan Moore's Red data (used as luminance) to create an interesting comparison with the famous Hubble image (Fig 1).



Fig.1

### M16 Eagle Nebula

Amateur (L) and Hubble Image (R) compared

Credit: Hubble Image (Jeff Hester, Univ of Ariz, Hubble team)

## Why use emission line filters for imaging nebulae?

Narrowband emission line filters have some interesting properties for nebular imaging. Because they only pass a narrow range of wavelengths, they can reveal a nebula's ionization structure by isolating particular emission lines such as hydrogen alpha contained within the nebula. For example, if a Sulfur, Hydrogen

and Oxygen filter set is used to create a tricolor image of a nebula, the various species can be visually differentiated through the resulting color contrast. Scientists analyze such images to gain insight into the ionization gradients of the nebula [Bessell2000].

While the spectra from a gaseous nebula will show specific emission lines, stellar spectra usually show absorption lines at these same wavelengths [Karttunen1987]. Thus at the wavelengths where a nebula glows, a star is dimmed. That property turns out to be useful for imaging nebulae in starry fields. Compared to an RGB image, the stars take longer to saturate because they are dimmed relative to the nebulosity. So it is easier to avoid bloomed stars when taking a deep exposure of a nebula if an emission line filter is used.

Emission line filters are very effective at suppressing light pollution, be it manmade or lunar. When the moon is shining brightly in the sky it reduces contrast by flooding the sky with broadband light. Even though the skyglow from the moon is bright, the energy is spread over a wide range of wavelengths. The intensity at any particular wavelength turns out to be quite low, so the amount of energy passing through an emission line filter due to the moonlight contribution to the skyglow is small. This means a high contrast nebular image can be taken despite an otherwise bright sky background.

Finally tricolor images such as the Hubble “Pillars of Creation” made using emission line filters have a unique appearance that is very different from RGB images. These images can offer a fresh new appearance to familiar objects and the associated color contrast reveals structural details that otherwise would be difficult to see.

For me that is the most exciting aspect of this imaging technique. The light pollution management just compounds the benefits: if the sky is clear I can image from my light polluted suburban backyard, no matter what the phase of the moon. This greatly increases the number of potential imaging nights per year.

## **Which emission line filters are most useful?**

The most common emission line found in nebulae is usually Hydrogen Alpha, “Ha” (656.3nm). The Halpha filter is the most important of the emission line filters. In RGB images the “Red” parts of the nebulae are primarily Hydrogen alpha emission.

The next most common emission line is probably the [Oxygen III] doublet (495.9nm and 500.7nm) “[OIII]”. The designator “III” means the Oxygen atom is doubly ionized (two electrons stripped off) and the brackets “[ ]” indicate it is a “forbidden” line; meaning it requires special conditions for the emission to occur [Goldberg1947]. Because there are actually two lines that are spaced closely together, it is called a “doublet”. The [OIII] doublet is what makes the blue-green color in many planetary nebulae.

The [SulfurII] doublet (671.6nm and 673.1nm) “[SII]” is commonly found in nebulae. The Hubble “Pillars of Creation” image was made using [SII] in combination with Ha and [OIII] filters. Because it is in the Red part of the visible spectrum and its wavelength is a bit longer than Ha, it is a deeper red color. Since a standard Red imaging filter will normally pass both the [SII] and Ha lines it can be hard to see contrast between Sulfur and Hydrogen-rich regions in a conventional RGB image. But using emission line filters, the [SII] and Ha data are assigned to different color channels making them easy to differentiate via color contrast.

Another important emission line is the [NitrogenII] doublet (654.8nm and 658.3nm) “[NII]” which is in the Red portion of the visible spectrum. Because it is so close to the Ha line, most Ha filters actually pass both the Ha and the [NII] lines. It therefore takes a very narrow bandpass Ha filter to exclude the [NII] lines. A 3nm or narrower Ha / [NII] filter set will split these lines however (Fig. 7b).

## Picking Targets and Choosing Filters

Good targets for tricolor emission line imaging include emission nebulae with or without star clusters such as The Rosette (Figures 2a & 2b), IC1805 “Heart Nebula” (Fig. 3), IC1396 (Fig. 4) and other such nebulae. For this class of objects, [SII], Ha and [OIII] filters are usually a good choice.

Planetary nebulae are good candidates for tricolor emission line imaging too. Some of the planetary nebulae may have significant [NII] as well as some of the Helium and Neon lines [Goldberg1947]. Good targets include the Helix Nebula, The Dumbbell Nebula, Emberson Jones 1 (Fig. 5) and so on.

Supernova remnants such as the Veil (Fig. 6a & 6b) or Crab (Fig. 7a-7c) nebulae are also excellent targets for tricolor emission line imaging. Good filter choices are [SII], Ha and [OIII].

It should be noted that reflection nebulosity is broadband and is not enhanced by emission line filters. If a nebula has significant reflection nebulosity, a good strategy might be to substitute a Blue filter for one of the emission line filters such as [SII], or [OIII].

## Exposures

As with Halpha imaging, exposure times typically are longer for tricolor emission line images compared to the RGB method. Depending on the specific object and optical system, subexposures usually aren't much shorter than five minutes and may run as long as 45 minutes or more. However bright objects like M42 are a notable exception.

One way to determine a good subexposure time is to take a one to five minute test exposure with 3x3 or 5x5 binning and check for saturated stars in it. Based on the results, compute the subexposure time for the image. For example if a one minute 5x5 binned exposure falls just short of saturating the brighter stars, then choose 20 to 30 minutes for subexposures as a first guess. Usually longer is better but avoid saturating stars or bright nebulae for the best results.

Common subexposure times are 10 to 20 minutes for an f/5 system to perhaps 15 to 30 minutes for an f/7 system. For an f/12.6 cassegrain 45 minute subexposures have been used with success. If the subexposure time becomes inconveniently long, consider binning 2x2 if appropriate considering desired final resolution and image scale.

To make subsequent image processing easier try to take a minimum of four to six subexposures through each filter. The more data that is taken the smoother the final image stack.

Unlike RGB images that are usually limited by skyglow noise, emission line images may be limited by dark current noise depending on conditions. Because the subexposures are often three to 10 times longer than RGB exposures, noise from dark current should be minimized by more aggressive sensor cooling if practical. For every four to six degrees C of additional cooling of the typical CCD sensor, there is a 50% reduction of dark current. So it takes about 12 to 18 degrees C of additional cooling to get about the same dark current noise for an exposure time increase of a factor of eight.

## Image processing

One of the processing decisions to make is the color palette to use. For [SII]/Ha/[OIII] imaging two color palettes are commonly used. The first one assigns colors in strict descending wavelength order: [SII] = Red, Ha = Green and [OIII] = Blue. This is the palette used by the Hubble team for the Pillars of Creation. Another palette that is commonly used assigns Ha to Red, [OIII] to Green and [SII] to Blue. The team at the Canada France Hawaii Telescope ("CFHT") have used that palette for a number of images with good results. Comparisons of these two palettes can be seen in Figures 2a/2b and 6a/6b.

Usually I prefer the Hubble Palette, but for some objects, such as the Veil Nebula, the CFHT palette looks better to me. Still there are times when my eye just likes an unconventional palette better. An example is the reverse wavelength ordered (shortest to longest) [OIII] = Red, Ha= Green, [NII] = Blue used for the image of Emberson Jones 1 (Fig. 5).

As mentioned above, it is good to take several long subexposures through each filter. The deeper the subexposures and the more of them, the lower the noise in the stacked frames. The typical set of stacked frames from a nebula imaged with

[SII], Ha and [OIII] filters will generally feature significantly more signal strength in the Ha stack than in the [SII] and [OIII].

To avoid having the Ha data dominate the overall color mix (Fig. 8a) the histograms of the [SII] and [OIII] frames should be stretched to look similar to the Ha histogram. This usually means that the [SII] and [OIII] data needs more total exposure time than for the Ha data to avoid a grainy processed image.. The lower the noise of the unprocessed stacked frames, the more aggressive the non-linear histogram stretching can be without introducing an unacceptable level of noise. If the final image is deemed too noisy, then smoothing programs can be used to make a more pleasing image. However processing artifacts can be introduced by smoothing. In general it is better to have more signal and less smoothing than the converse.

Process each filter's stacked data separately before combining into a color image. It may be necessary to repeat the processing and stretching and color combining a few times to get a good color mix. Seek a neutral background color and avoid saturating the brighter parts of the nebula. When the histograms and levels are properly adjusted, there should be all colors in the nebula, not just a single dominant color (Fig. 8b).

Once the overall desired color balance is reached, the stars might have odd colors and or colored haloes surrounding them. Because the three emission lines used for the image may not perfectly represent Red, Green and Blue, the star colors may not be true. Additionally the histogram stretching needed for color balance can bloat the stars in their assigned color channels.

Depending on the goals for the image, these anomalies may or may not be acceptable. If the latter, there are solutions for both. One way to fix the stars to better match those in an RGB image, is to copy and paste stars from an RGB image into the emission line image. Since the RGB image is used only as a "star donor" it is not necessary to take a large number of "deep" exposures.

Because the emission line images from the Hubble team and other such professionals often have haloed stars that are strange colors, I am not bothered by those characteristics in my images. Ultimately the decision to edit the stars is a matter of personal taste and the specific goals for the image.

If a full RGB or LRGB image of the target nebula is available, it is also possible to blend that data with the emission line data to make an image that enjoys the best of both methods: more natural looking stars with vivid nebulosity and enhanced visibility of faint stars and background galaxies (Fig. 9).

## **Example Image processing: IC1848**

When processing the image data, first start with stacked calibrated data for each filter. An example of a typical data set can be seen in Fig. 10. The H $\alpha$  data usually is well defined, while the [SII] and [OIII] data often can be quite faint.

Image processing will be performed on each individual data set. The goal is to make three nice looking monochrome images with similar background level that can be later combined into a tricolor image. Customary processing such as DDP, levels, curves and filters are generally applied to the stacked data to reach that goal.

Often a simple application of DDP, with careful attention being given to the background level parameter will greatly enhance the image. Try to set the background level somewhat below the "auto" setting to avoid truncating the left side of the histogram. Sometimes iteration is required to optimize the image appearance (Fig 11).

Next import the data into Photoshop CS in FITS format and then apply curves, levels and selective unsharp masking to bring out the best detail in each image (Fig. 12). Then save each image and open them images in Maxim DL for color combine. Color combining can be also done in Photoshop CS (Fig. 13).

Usually the color balance is not quite optimum at this point so save the image in 16 TIFF mode and once again open in Photoshop CS and make final levels, color balance and curve adjustments and fix any star haloes or blooming spikes to create the final color image (Fig. 14).

## **Closing and acknowledgements**

Tricolor emission line imaging can offer new realms for astro-imagers to explore. Not only does the method offer advantages in dealing with light-polluted skies, the resulting images have a unique appearance previously seen only in professional images (Fig 1). Emission line data can be combined with broadband data to give the imager even more powerful options for creativity.

I would like to thank Al Kelly for contributing his LRGB data for Emberson-Jones 1 and for processing the composite image (Fig. 9). Also my appreciation is extended to Mike Cook for conceiving of and creating the comparison to the Hubble Pillars of Creation image (Fig.1) and to Stan Moore for contributing his Red data for that effort and for originally suggesting that I write this article. And of course many thanks to my wife Christel for her support in this endeavor

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Fig. 2a  
Hubble Palette



Fig. 2b  
CFHT palette

### **Rosette Nebula** (2 x 1 mosaic)

Open cluster with nebulosity

20 minute and 30 minute subexposures at f/4.5 (F=457.5mm)

6 hours 40 minutes total exposure (2 x 3 hours 20min)



Fig. 3

### **IC1805 Heart Nebula**

Hubble Palette

Aggressive Histogram Stretching to bring out the blues

10 minute subexposures at f/5 (F=530mm)

6 hours total exposure time



Fig. 4  
**IC1396** widefield mosaic (2x1)  
Hubble Palette  
10 and 15 minute subexposures at f/5 (530mm)  
pushed the histograms aggressively  
18 hours total (2x9 hours)



Fig. 5  
**PK164+31.1 Emberson Jones 1**  
Custom Palette (increasing wavelength order)  
([OIII] =R, Ha =G, [NII] =B)  
Planetary Nebula  
shot under a full moon  
don't feel constrained by standard palettes, let the eye guide  
15 minute subexposures at f/7 (F=1085mm) binned 2x2 to speed up exposures  
5 hours 15 minutes total exposure time





Fig. 6a  
Hubble Palette  
(Ha=R, [OIII]=G, [SII]=B)



Fig. 6b  
CFHT Palette  
([SII]=R, Ha=G, [OIII]=B)

**Network Nebula (part of Veil Nebula)**

Supernova remnant

Binned 2x2 to accelerate exposure time

20 minute subexposures at f/7 (F=1085mm)

four hours total exposure

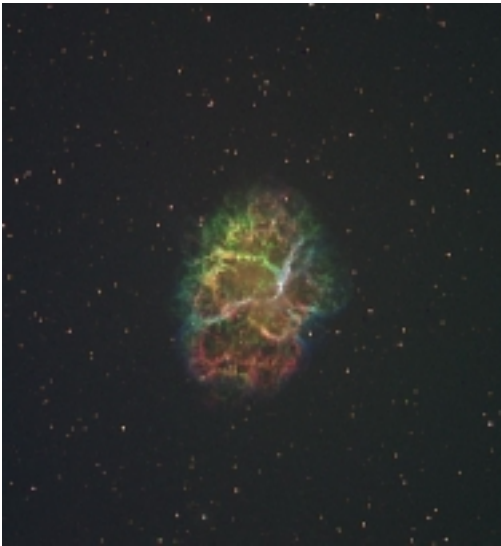


Fig. 7a

**Crab Nebula**

Hubble Palette

Supernova remnant

Notice how broadband cloud in center (synchrotron radiation) is removed by emission line filters

Deep exposures: 45 minute subexposures at f/12.46, (F=4430mm)

6 hours and 45 minutes total exposure time



Fig. 7B

**Crab Nebula**

Custom Palette

(Ha=R, [NII]=G, [NII]=B)

Possible to split closely-spaced Ha and [NII] lines with slow (f/12.46) scope

If lines were not split, then image would only be gray color

45 minute subexposures at f/12.46 (F=4430mm)

4 hours 30 minutes total exposure time



Fig. 7C

**Crab Nebula**

Custom Palette, "wavelength ordered"

([SII]=R, [NII]=G, Ha=B)

**All data from Red portion of spectrum**

Could not see this differentiation in RGB

45minute subexposures at f/12.46 (F=4430mm)

6hours 45 minutes total exposure time



Fig. 8a



Fig. 8b

**NGC6820/NGC6823 area**

Before and after histogram and levels adjustment



Fig. 9

**PK164+31.1 Emberson Jones 1**

Al Kelly Blended his LRGB data with the author's [NII], Ha and [OIII] data (in descending wavelength order)

This accentuated the central star, gave more natural star appearances and revealed the background galaxies

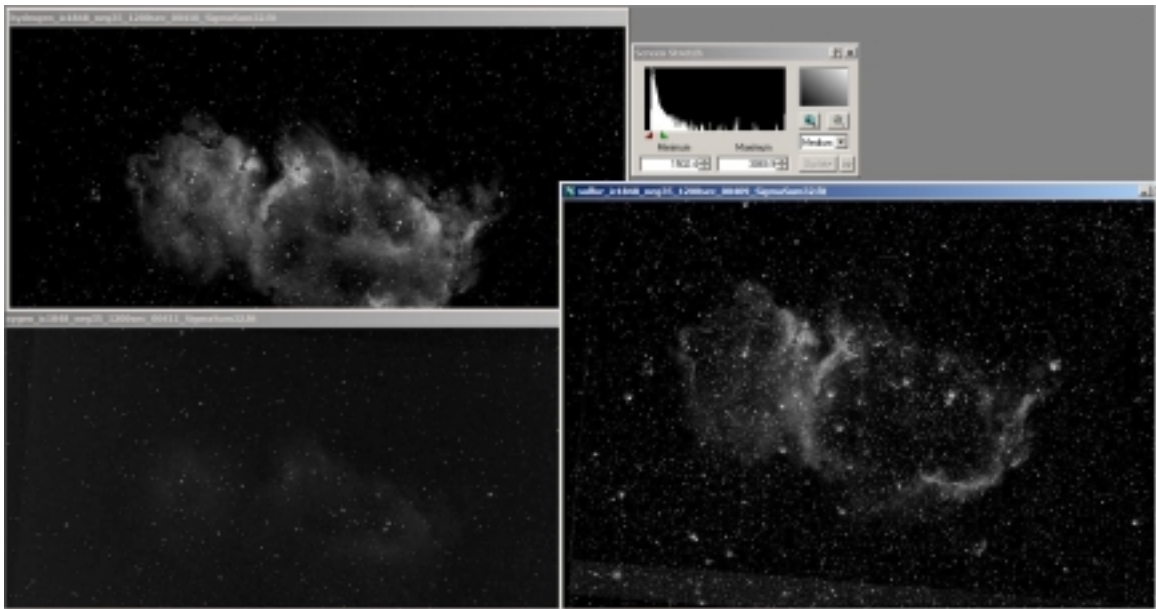


Fig. 10  
Initial stackup of raw calibrated data. Clockwise from upper left: Halpha, [SII], [OIII] (Maxim DL)

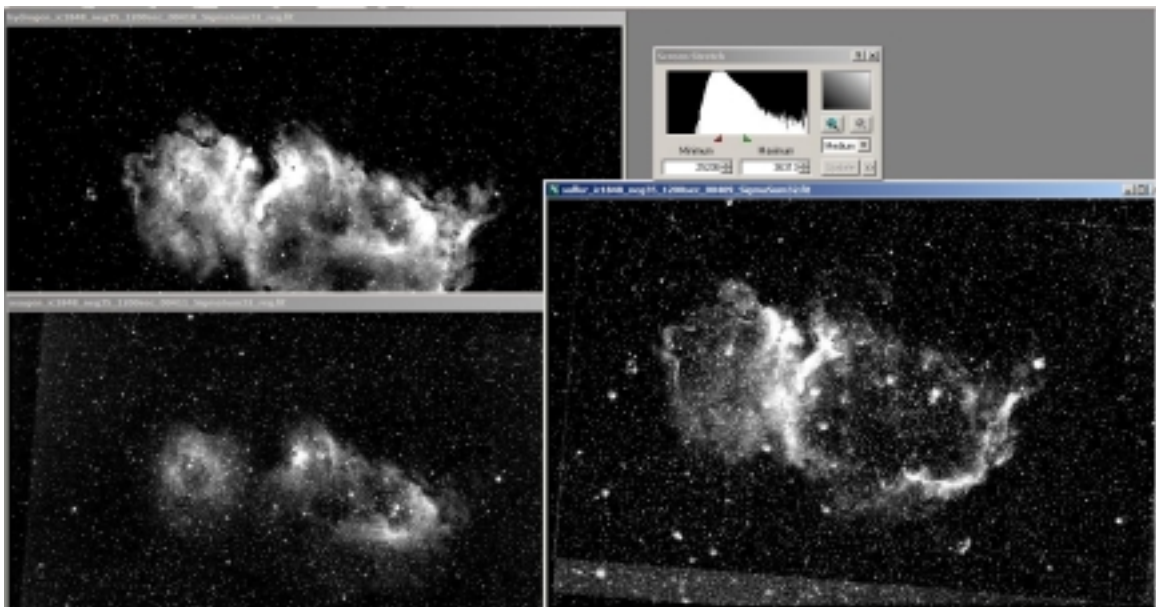


Fig. 11  
DDP processing applied to stacked data (Maxim DL)

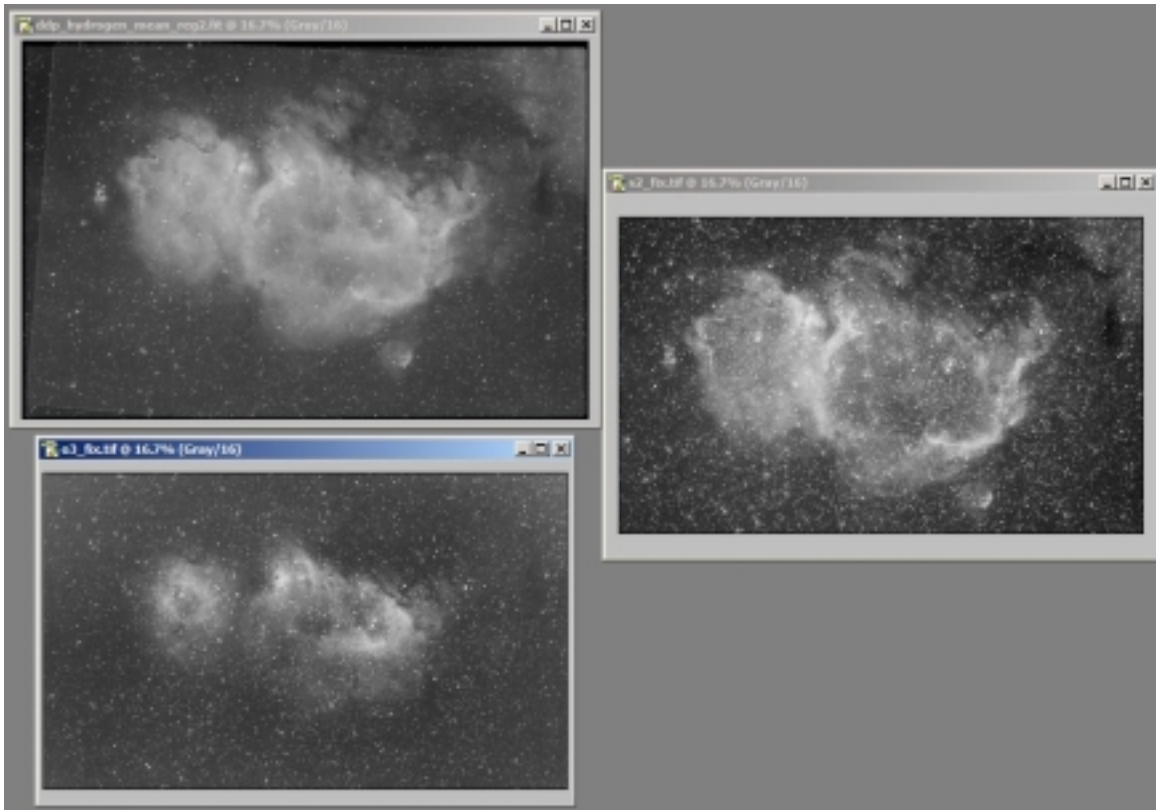


Fig. 12  
Curves and levels adjusted in Photoshop CS (16 bit mode, imported as FITs data)



Fig. 13  
Initial color combine (Maxim DL)





Fig. 14

Final color adjustment, star repairs (Photoshop CS)

Aggressive histogram stretching to bring out blues

Deep exposure: 20 minute subexposures at f/5 (F=530mm)

Twelve hours total exposure time