TrueColor-Plus SHORGB Script—The Underlying Model and Derivation of Equations

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# Ground-Work:

This script strives to separate an image into two constituent parts: an emission-line component (L) and a background component (Z). Upon achieving the separation, the L component can be amplified and combined into the RGB image. Alternatively, the L component(s) can make a separate narrowband image free of the less meaningful background (Z) components of the narrowband image. This exercise is analogous to separating signal from noise. We isolate the signal so that we can amplify it without also amplifying the noise.

Compare this approach to the approach that simply blends a narrowband image, amplified by some factor, with a broadband image. The entire narrowband image's amplification means its emission line (or signal) and its background (or noise equivalent) are amplified before adding it into the broadband image. The separation process requires we have a model for the background and line components of our images. This script's simple one is described after I elaborate further on this unwanted background's origin and nature.

# The Background – What is it?

The image background component, in both the narrowband and broadband images, comes from two sources. The first source is a pervasive, slowly varying radiation level across the narrowband and broadband filters’ bandwidth. Figure 1 illustrates the background radiation's omnipresence spanning the visible part of the spectrum: The region between the zero on the y-axis and the horizontally trending wiggling line. The emission lines, vertical spikes, arise from this background trend. The radiation that contributes to the background comes from many different and mostly inseparable sources, including emissions from molecular transitions, ionic transitions, free-free transitions, collisional transitions, bond vibrations, rare transitions in atoms we don't care about, and more.

A second source, or actually the same source, but seen from a different perspective, arises from the fact that narrowband filters admit radiation outside of the emission line's range proper. Figure 2 shows the acceptance width of such filters. Therefore, they do not include just the background that lies directly below the thin emission line and the background on either side. For our proposes, these two sources explain what we see in our final output images compared to ordinary SHO and SHORGB images, but background is just background for our computational purposes.

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| *Figure 1: A spectrum of the Orion Nebula. Everything below the wiggly horizontal line is background radiation. The emission lines extend above that background. Assume that the distance between the two vertical red lines represents the capture bandwidth of a filter. Clearly, the image would contain both the emission line and the background below it. (From BU web site.)* |

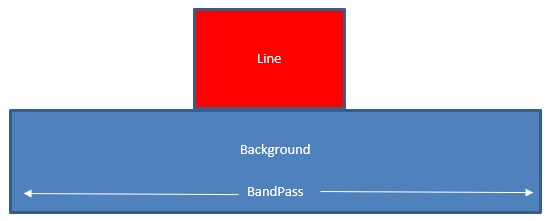
|  |
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| *Figure 2: The relationship between the width of an H*α *line and the bandwidth of a narrowband filter. This illustrates that narrowband filters admit radiation from other than the emission line itself, from longer and shorter wavelengths. This extra radiation constitutes part of a narrowband image's background.* |

To separate the background (Z) from the emission line (L) components in our image, we need a model. The next section describes the one I used in this script.

# Background – Line Model:

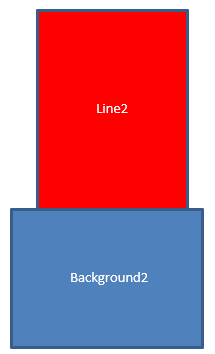
We have only two observations, a narrowband image and a broadband image that encompasses the narrowband image, to separate the line from the background. For example, the narrowband image might be taken through an Hα filter, and the corresponding broadband image would be the red-filter image. With only these two observations, and two unknown values (L and Z), our model choices are minimal! (Indeed, we cannot even allocate one degree of freedom to characterize the omnipresent noise in our images! This means we must live with the full impact of the noise in our images propagating into our separated background and line components.)

Figure 3 illustrates, schematically, the background-line model for a single pixel.



*Figure 3: A straightforward model of the relationship between the intensity of the background (blue) and the emission line (red) in a single pixel of a broadband image.*

Consider a second image, a narrowband image, with a smaller bandpass and probably a longer exposure time than used to collect the broadband data. (The exposures could be the same, no matter.) A pixel in that image, covering the same patch of sky as the pixel in figure 3, might be sketched as in Figure 4.



*Figure 4: A schematic of a pixel's intensity, in a narrowband image, relative to the same pixel, covering the same patch of sky, and in Figure 3. The exposure here is drawn as if it were longer than that in Figure 3 (not a requirement), as, of course, this pixel sees a smaller bandwidth.*

As hinted above, these two-pixel intensities of the same sky location (aligned pixels) give us two simultaneous equations for the background and emission line:

B = L + Z ,

N = L(EN/EB) + Z(EN/EB)(WN/WB) ,

where B and N are the broadband and narrowband images, the E's represent the image exposure times, and the W's represent the bandwidths of the broadband and narrowband filters. These equations can be solved to give L and Z intensities for each pixel and each point in the sky recorded in the two images’ aligned images.

Suppose two emission lines reside in the same broadband image. In that case, the correct way to isolate and amplify both of them requires three simultaneous equations: one for the broadband image and one each for the narrowband images. Again, we solve these three equations for each emission line's intensity and the background intensity, subject to our simple model.

# Implementation:

The pixel-by-pixel solution for the above model, yielding estimates for the isolated emission line intensities in each pixel, has been implemented as the PixInsight Script, **TrueColor-Plus SHORGB**. That script can be used to extract the emission lines for use outside of the script, perhaps to make an SHO image, or within the script, to augment the line contribution(s) to an RGB image.

# Acquiring the Script:

The current version of the script and documentation are available by downloading the folder at this link:

<https://www.dropbox.com/sh/dpd1zs5fl576ohh/AACtBkC16yB2EiqRuhBDmfxga?dl=0>

# Installation:

Installation procedures follow standard PixInsight protocols. Place the download folder in an accessible and stable location; open the Scripts tab in PixInsight; select Feature Scripts; select Add; Point the function to the downloaded folder and press the Done button when PixInsight completes its task.

# Usage:

Because of the approach used, the separating of Z and L, this script applies to linear images only and only to aligned and integrated subs that have not undergone any processing, except possibly Mure Denoise.

The following discussion refers to the script's user-interface shown in Figure 5.

## Views Selectors:

Below the description text box, broadband and narrowband images can be selected from drop-down lists. All three broadband images are required, but all, some, or none of the narrowband images may be selected for inclusion in the final image. (What tasks you can pursue depends on the images you include.)

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| *Figure 5: User interface for* ***TrueColor-Plus SHORGB.*** *This figure shows it at start-up with the default settings.* |

## Sliders:

Among the sliders are the three left-justified with labels including the word "Factor." These three sliders determine the multiplication factors applied to the line, L, components of the images intended for recombination with the R, G, and B images before becoming an RGB image. Of course, the Hα affects the red broadband image, SII also affects the red image, and OIII affects both the blue and green images. Setting all three sliders to approximately equal values tends to produce nearly correct color balance in the output image, which, in turn, responds well to color calibration by the PhotometricColorCalbration process. In fact, in many cases, the output image looks similar to an unenhanced RGB image, with a noticeable added emphasis on the regions where emissions lines are strongest. I guess," no great surprise here," since most of the image color usually arises from the emission lines in their natural ratios, which equal scaling maintains.

The "Hb Factor (%)" slider determines how much H-beta is added to the blue-filter image. There is no Hβ narrowband image involved, and none is needed. It's a fact that where there's Hα, there's Hβ! Internet wisdom suggests that Hα/Hβ = 2.92, (~34% Hβ) or thereabout. The default setting for the Hβ Factor slider reflects that value.

Finally, the "OIII Blue %" sets the blue/green ratio of the OIII contribution. The natural value lies close to a 50-50 mix, the default setting in the program. The precise value to use for the most realistic rendering is difficult to ascertain. The definitions of "blue" and "green" differ in the literature, no less among causal discussions naming the OIII colors "robin's-egg blue" or "teal," or "aqua," and other vague terms. These color terms do not have universal definitions and do not help define the OIII color. To some degree, this problem affects the other narrowband colors as well, especially Hβ. (Does anyone have the hex codes for the emission-line colors? If so, please let me know!)

## Value-Entry Boxes:

The relative filter widths and relative exposures also figure into the equations used to separate the Z and L image components. Set them appropriately. The units used do not actually matter, as long as they are consistent.

## Checkboxes:

The checkboxes allow specifying which images, in addition to the default RGB image, display at the termination of the script. Also, the script utilizes a few intermediate images. The right-hand checkbox allows deleting those images automatically.

## The Blue Triangle:

Because iterating on various input values may be desirable, I have implemented an "instance" capability. By setting your parameters then dragging an instance icon, you can retain your settings by dragging the blue triangle in the lower left to the desktop. To use or adjust the settings, double click the desktop instance. A small window opens. Single-click the blue circle, and the dialog, with your parameter settings, opens.

## Iterating:

A user of this script may desire to iterate using different mixing parameters or even different images or masks. This can be accomplished by checking the box at the lower right. This causes the dialog to reopen after the script executes and display the last settings—ready for subsequent adjustments.

# Reporting Problems & Submitting Suggestions:

Please let me know of any bug you uncover; contact me at [Alex@FaintLightPhotography.com](mailto:Alex@FaintLightPhotography.com). Include a description of the problem and any error messages generated. Also, describe the data and procedures that led to the error.

# Future Possibilities:

One obvious road to explore involves combining information from a Luminosity image by adding its equation to the above equations. This may allow a somewhat more complex model, perhaps with a nonuniform background across the span of emission-line wavelengths or some allowance for uncertainties/errors. Alternatively, perhaps imagers could be cajoled into taking narrowband images through two different bandwidth narrowband filters. Most likely, that would provide considerable uplift to the background-line separation solution by keeping it very locally centered on the emission lines themselves, thereby increasing the background estimation's relevance and accuracy. Perhaps this approach would be more easily implemented by professionals if they had such interests.

Although probably quite secondary in importance, I may add the ability to specify different bandwidths and transmission efficiencies for different filters.

Suggestions for additions and improvements can be submitted to me at the same email as above.

# Quirks & Foibles:

1. Before dragging an instance-icon to the desktop, take the precautions that entered values along with that instance-icon. If you edit a dialog box (or other items?), you must exit that dialog box before dragging the icon to the desktop, or that last-edited item is not captured.
2. Black regions often appear around the stars and at other places in the emission-line images. Mathematically, these are areas where the calculated background values equal or exceed the calculated value for background+emission line. The distribution of where this occurs indicates anomalous behavior. Its association with bright stars suggests it is an artifact of the image acquisition: an effect of scattered light. Suppose you want to subdue this effect at the expense of accuracy elsewhere in the image. Then, the black-area artifacts can be decreased by Increasing the bandwidth of the broadband filter. This remediation undoubtedly sacrifices the accuracy of the emission-line values.

# Known Bugs:

None known.