

# Technique for Combining Continuum and Emission Wavelength Data in Astrophotography

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## Continuum Spectrum (Broadband) Data

Colour images in astrophotography are either created using a one-shot-colour (OSC) camera or a mono camera in which red (R), green (G) and blue (B) filters are used sequentially. In the case of a OSC then R, G and B filters are applied over individual pixels in a Bayer pattern, by the camera's photosensitive sensor manufacturer. In both cases a colour image is created that consists of the combination of red channel, green channel and blue channel to create a colour or RGB image. Each colour channel represents light of a continuous range of wavelengths. Typical ranges of wavelengths assigned to each colour using RGB filters are:

Red: 100nm continuum wavelength in the range 600-700nm

Green: 100nm continuum wavelength in the range 500-600nm

Blue: 100nm continuum wavelength in the range 400-500nm

Although our RGB image only consists of red, green and blue data, the relative brightness of each of the three colours, when they are adjacent to each other, is interpreted by the human brain as a continuous spectrum of colours.

Continuum spectrum wavelength data is typically used to create 'true colour' images of astronomical targets.

*Galaxy M81 – A 'true-colour' RGB Image*



The above image of M81 was taken with a 'one-shot-colour' camera using an Optolong L-Pro filter that allows a broadband continuum range of visible light wavelengths to produce a 'true-colour' RGB image.

### Emission Line and Narrowband Data

A property of certain atomic elements, that are found in astronomical molecular clouds or nebula, is that they emit light at very specific wavelengths when excited by energetic stars in close proximity. For example, the following elements are commonly found in astronomical nebula and when excited they emit light at:

Ha (Hydrogen alpha) 656.5nm (red part of spectrum)

Sii (Sulphur 2) 671.7nm (red part of spectrum)

Oiii (Oxygen 3) 500.7nm (green/blue part of spectrum)

Narrowband photographic filters are designed to pass a narrow range of continuum wavelengths of light centred on one of the specific emission wavelengths. For example, a common filter used to pass Ha emission lines has a narrow continuum of a 7nm range of wavelengths centred on 657nm.

*Nebula IC410 – A 'false-colour' HOO Image*



The above image of IC410 was taken using a 'one-shot-colour' camera equipped with an Optolong L-eNhanse filter. This is a narrowband filter that only passes light at the wavelengths of the emission lines of Oiii and Ha with a narrowband of spectrum in a continuum range of 10nm centred on each of the emission line wavelengths. In this image the Ha data has been assigned to the images R channel and the Oiii to each of the image's G and B channels. For this reason, this type of image is referred to as an HOO (hydrogen-oxygen-oxygen) image rather than an RGB (red-green-blue) image.

The advantage of using a narrowband pass filter is that by excluding all wavelengths of light other than the narrow continuum range centred on the emission line wavelength, a greater contrast is created to give enhanced clarity of the emission nebula. If only one narrowband filter is used then a high contrast mono-image of the emission line nebula is created. If a sequence of different filters is used, then their images can be assigned to different R, G and B channels to create a 'false colour' image of emission nebula with each colour representing a different emission element within the nebula.

The disadvantage of narrowband filters is that they only let a fraction of the light reach our camera sensor compared to using a broadband filter or no filter at all. To compensate for this the camera may need to be set for a longer exposure time or a more sensitive gain setting or a more sensitive pixel binning.

### **Why would we want to combine a full continuum of RGB Data with Emission Data?**

There are many examples where we image an object that is predominantly a full continuum spectrum object, a galaxy or a reflection nebula for example, but it also contains emission line nebulae components. Capturing both a full spectrum RGB image and narrowband emission image which are then combined may reveal more information about the object and create a more interesting and complete image.

## The Principles for Combining Broadband and Narrowband Data

Combining RGB continuum spectrum data with emission or narrowband data is not the same as combining different narrowband data sets to create a false colour wholly narrowband based image. When we create an image from purely narrowband data, we simply assign the different filter data to each of R, G and B channels, while still in the linear state, to create the combined image.

When we combine complete RGB data with additional emission data, for example Ha combined with the red continuum data, then we are combining the full spectrum red with the Ha data in the same R channel. The technique for doing that, described here, combines the data when it is already processed and in the non-linear (stretched) state. Combining non-linear images presents the challenge of potentially over exposing the new combined image and losing data. We cannot simply add two non-linear images together and expect to create an artefact free new image. The following process overcomes that challenge when we are combining full continuum RGB data and narrowband data.

The process has four stages:

1. Equalise the luminosity of the narrowband spectrum continuum with the broadband spectrum continuum.
2. Isolate the emission data from the narrowband continuum data.
3. Process the RGB and emission data independently to create non-linear images.
4. Combine the RGB and emission data to create a single image.



## Equalise the luminosity of the narrowband spectrum continuum with the broadband spectrum continuum.

Even the best photographic narrowband filters are not capable of only passing light at the specific wavelength of the emission lines that we are intending to capture. All pass light at a narrow continuum of wavelengths centred on the emission wavelength. Our narrowband image will consist of the emission data that we want and the continuum spectrum data limited to the range of the band pass of the filter.

For example:

- A broadband red, green or blue filter will typically pass light in wavelength range of 100nm (600-700nm for the red filter) to capture the entire spectrum of light.
- A hydrogen-alpha (Ha) narrow band filter may pass light with a wavelength continuum range of 7nm (653-660nm) that includes the Ha emission wavelength of 656.5nm.
- The continuum spectrum passed by the narrowband Ha filter will be much dimmer than the spectrum passed by the broadband R filter. In fact, it will be only 7% as bright (7nm band pass compared to 100nm band pass for a full red filter) for the same exposure settings. To partially compensate for this the narrowband image is usually recorded at a different exposure setting through either: a longer exposure: different camera pixel binning; or different camera gain setting.

The important points are:

- A. The narrowband data consists of spectrum continuum data as well as emission line data.
- B. The narrowband continuum data will be at a different brightness compared to the corresponding broadband continuum data. The difference will depend on the relative difference of the filter band pass ranges and the different camera exposure settings used during image capture.

The first step in combining our full RGB data and narrowband data it to separate the emission line data for the narrowband continuum spectrum data. To do this we will make use of our broadband red (R) data if its Ha that we are combining with it. (*For Oiii emission we would more likely make use of the broadband green (G) data*). Proportionately, the R data is mainly continuum spectrum data with a very small percentage of Ha emission line data. The Ha narrowband data on the other hand, has a high proportion of emission line data plus a narrow range of continuum spectrum data.

### Process in PixInsight:

#### 1. Boost the narrowband continuum data to match the luminosity range of the R continuum data.

To boost the overall brightness of the continuum data in our Ha image to match the brightness of the continuum data in the R image we can use a trick in PixInsight to make use of the Colour Calibration tool for a purpose that it was certainly not designed for<sup>1</sup>.

First, calibrate, register and integrate the original sub-exposures to create a linear full continuum spectrum red 'R' image (along with the 'G' and 'B' images that will be used

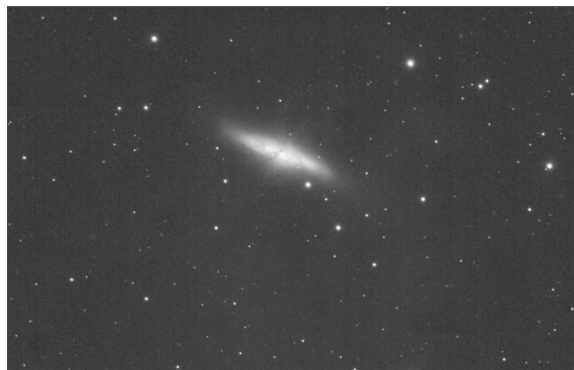
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<sup>1</sup> [Advanced Narrowband Combination — Pixinsight Tutorial — Night Photons](#)



later to create the RGB image) and separately the integrated linear narrowband Ha image so that they are star aligned with each other.

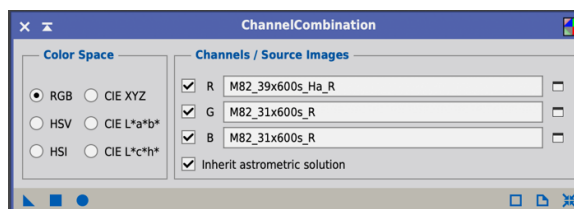
**M82 – Linear image of the R component of a full 100nm spectrum continuum.**



**M82 – Linear image of the Ha emission and a narrow 10nm continuum spectrum.**



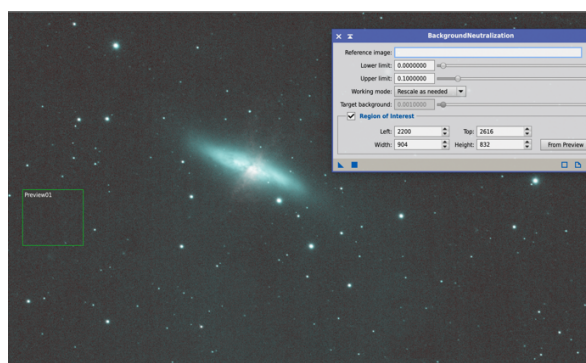
Use the PixInsight Channel Combination process to create an RGB image in which the Ha linear image is assigned to the red (R) channel and the R linear image is assigned to each of the green (G) and blue (B) channels.



This creates an HaRR (hydrogen-red-red) image which we are simply using as a container that has the narrowband continuum and emission data in the R channel; and the broadband red continuum in the G and B channels.

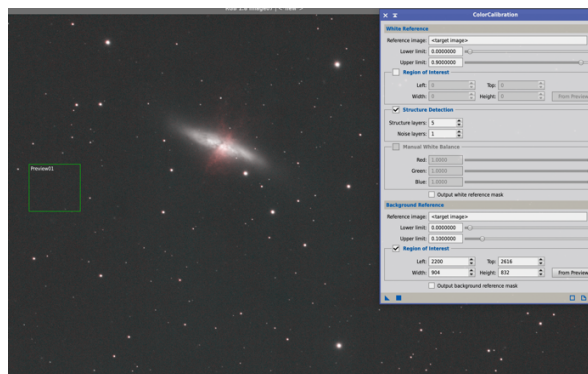
**Note:** If we were using a different narrowband filter, for example Oiii, then it may be more appropriate to combine it with the green or blue broadband continuum data.

Next, select a neutral part of the HaRR background as a preview and use this as a reference for the PixInsight Background Neutralisation process.



Now for the trick, apply the PixInsight Colour Calibration process using the whole target image and structure detection for calculating the white balance and the neutral background preview for background neutralisation.

The stars in the HaRR image should now be a neutral white colour.



The colour calibration process will adjust the overall luminosity in each colour channel so that they are balanced. In our example, the G and B channels will not change as they contain exactly the same data, the broadband red continuum data that we assigned to both channels. The R channel however contains our dimmer narrow band data. The colour calibration process will boost the narrowband data assigned to the R channel to match the broadband red data's luminosity that we assigned to each of the G and B channels.

The PixInsight process console will identify the factors applied to each of the R, G and B channels to match their luminosity to achieve colour balance. In this example the W:G and W:B channel factors were exactly 1.0 as expected, in other words they had not changed. The W:R channel however, had been increased by a factor of 4.4537.

In other words, even though the camera gain had been set for a higher sensitivity when taking the images with the narrowband filter, the Ha image still had to have its luminosity increased by 4.45 times to match the luminosity of the full spectrum red component image. The PixInsight Colour Calibration process has calculated and automatically increased the Ha luminosity to match the luminosity in full continuum red data.

Our colour calibrated HaRR image now contains Ha emission line and continuum data in the R channel whose overall luminosity has been boosted to match the red continuum data in the G and B channels. Remember that this image has not been created to actually be an image, it has been created to act as a container so that we could manipulate our narrowband Ha (continuum and emission line) and broadband red (continuum) data relative to each other. The colour calibration process has been utilised as a mechanism to boost the narrowband continuum data to match the luminosity in the broadband continuum data.

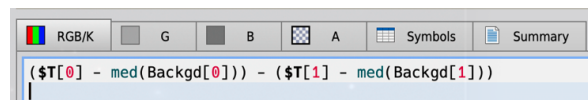
Referring to the channels in this image as R, G and B is a little misleading because they certainly don't contain red, green and blue data. In fact, they are all red data or at least Ha-R-R. For the next stage of the process, we will use PixelMath to create a pure Ha emission line image from this HaRR image. In PixelMath the R channel of an image is referred to a [0], the G channel as [1] and the B channel as [2].

## Isolate the Emission Data from the Continuum Data

Now that we have our HaRR image with the luminosity of the narrowband continuum data in channel R or [0] equalised with the luminosity of our broadband red continuum data in channel G or [1], we will use PixelMath to isolate the emission line data from the narrowband continuum data. This will leave us with an image that is pure Ha emission line data.

The first step is to create a preview in our newly created HaRR image on a neutral part of the background sky. Drag the preview onto the PixInsight desktop to create a new image and give it the identifier 'Backgd'.

Now apply the following PixelMath expression to the HaRR image:



$$(\$T[0] - \text{med}(\text{Backgd}[0])) - (\$T[1] - \text{med}(\text{Backgd}[1]))$$

In the M82 example the image opposite is created. This is a pure Ha emission line wavelength image without any of the continuum spectrum wavelengths that had been passed by the narrowband filter.



So, what did the PixelMath expression do?

**\$T** refers to the **Target** image that the PixelMath expression is being applied to.

**\$T[0]** refers to the target image pixels in channel 0 also known as the R channel.

**\$T[1]** refers to the target image pixels in channel 1 also known as the G channel.

**Backgd** is the image that we created from a preview of a section of the HaRR image's neutral background. It is a copy of that part of our main image and includes the same data as that part of the main image in each of channel 0, 1 and 2 also known as R, G and B.

**med(Backgd)** is the median value of all of the pixels in the Backgd image. This is a robust estimate of the pixel values of the background skyflux in our image.

**\$T[0] - med(Backgd[0])** is the pixel value of our narrowband **continuum and emission line** data in channel 0, i.e. the R channel, after subtraction of the background flux.

**\$T[1] - med(Backgd[1])** is the pixel value of our red **continuum** data in channel 1, i.e. the G channel, after subtraction of the background flux.

The whole expression therefore says set the pixel value in the image to equal the continuum plus emission line data (channel 0) minus the continuum data (channel 1); in other words, just the pure emission line data is left.



## CONTINUUM + EMISSION – CONTINUUM = EMISSION

In this case we set the PixelMath to use a single RGB/K expression so that the whole HaRR image has now been converted to a monochrome Ha image.

Set the PixInsight colour space for the image to 'convert to grayscale'.

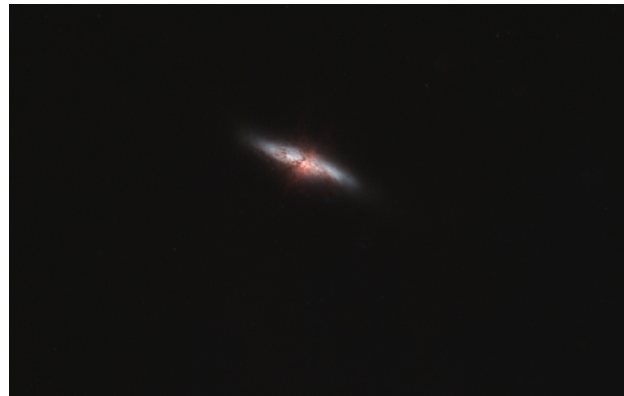


We now have a pure Ha emission image, with all continuum data removed. The HaRR image has been converted into a pure Ha image.

## Process the RGB and emission data independently to create non-linear images.

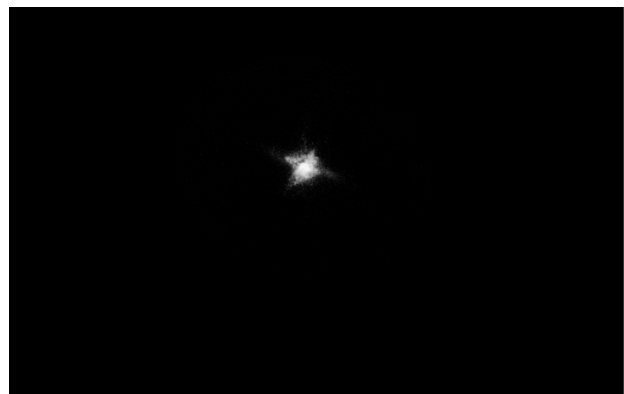
The third stage is to separately process the broadband RGB image and Ha emission image to create completed non-linear images.

The red, green and blue broadband continuum spectrum integrated images can be combined to create a single **RGB** image. Spectrophotometric colour calibration will provide highly accurate true-colour. The stars in the image are removed with StarNet2. The galaxy image and the stars image are then processed separately in the usual way to create non-linear images.



The **Ha** emission image is also processed in the usual way to create a non-linear image. The stars are removed.

It is important to keep the background in this image as black as possible. If this is not done there is a likelihood of introducing a colour tint to the combined image at the final stage.



In this example the spectrophotometrically colour calibrated stars extracted from the RGB image are also separately processed to a final non-linear state.

The separate components of the non-linear images must now be combined to create our final and complete image.



## Combine the RGB and emission data to create a single image.

Non-linear images cannot simply be added together as bright pixel data added to bright pixel data may exceed the maximum pixel value, meaning that it is overexposed and clipped. The data information in the pixel value is lost.

PixelMath denotes pixel values in the range 0-1 with the bit depth of the value determined by the bit depth chosen for saving the image in XISF format. The maximum bit depth is 64-bit or  $1.8 \times 10^{19}$  steps between 0 and 1. The value 0 denotes full black and the value 1 denotes full white.

The following PixelMath function will combine two non-linear images, without the result being able to exceed 1.0

$$\sim(\sim\$T * \sim\text{Image2})$$

The  $\sim$  (tilde) function in PixelMath represents the  $1-x$  function, where  $x$  is the operand that the function operates on. This effectively inverts the pixel value. Black (0) becomes white (1) and vice versa.

As  $\$T$  in PixelMath simply means the target image, the function is the equivalent of:

$$1 - ((1 - \text{Image1}) * (1 - \text{Image2}))$$

' $1-\$T$ ' inverts the target image pixel values. Bright pixels become dim ones and all values will be between 1 and 0. Multiplying  $\sim$  target image by the  $\sim$ image2 value will give a smaller value between 0 and 1, i.e. it will be dimmer. Inverting this product value again with  $1-(a*b)$  will cause the dimmer product to now be brighter, but with a value of less than 1.

So, the simplest PixelMath expression for combining the Ha image with the RGB image is to uncheck the 'Use a single RGB/K expression' and apply the following to each of the R, G and B channels in the PixelMath expression editor:

```
// R:  $\sim(\sim\$T * \sim\text{Ha\_Image})$ 
// G:  $\$T$ 
// B:  $\$T$ 
```

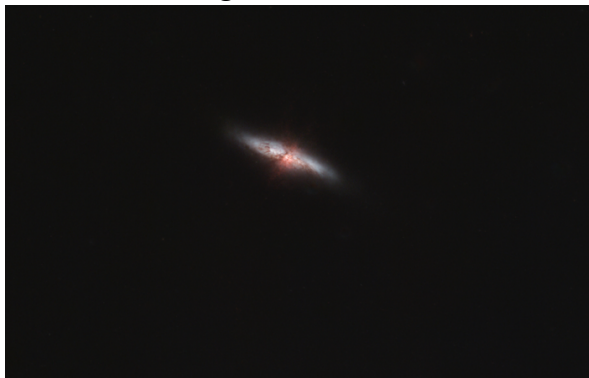
The RGB image is the target image. The red channel will combine with the Ha data. The green and blue channels will simply remain as the target image data.

A variation of  $\sim(\sim\$T * \sim\text{Ha\_Image})$  is:

```
// R: $T * ~L + L * ~(\sim\$T * ~Ha_Image)
// G: $T
// B: $T
// Symbols: L = 1
```

The variation allows us to adjust the value of L, between 0 and 1, to reduce the effect of combining 'Ha\_Image' with the target image. In most cases the default value of L=1 will give the best result.

**RGB image before combination with the Ha emission image.**



**HaRGB image after combination with the Ha emission image.**



The M82 image is completed by the addition of stars extracted from the RGB image earlier in the process. Combining the non-linear processed stars image with the galaxy image uses the same PixelMath expression that we used to combine the Ha and RGB images:  $\sim(\sim\$T * \sim\text{Stars})$  in its simplest form.

*Galaxy M82 – An HaRGB Image*

