Color the Universe!
Learn how to make astronomy images

Travis A. Rector

University of Alaska Anchorage and NOAO
Department of Physics and Astronomy
3211 Providence Dr., Anchorage, AK USA
email: tarector@alaska.edu

Introduction

A Note from the Author

Have you ever wondered how astronomers make beautiful color images of space? Have you ever wanted to make *your own* images of space? This tutorial will teach you how astronomers make color images with the world's largest and most powerful telescopes. These techniques are used to create many of the astronomical images you see from *Kitt Peak National Observatory*, *Gemini Observatory*, and of course the *Hubble Space Telescope*. In this tutorial you will learn how to make an image of M33, the Triangulum Galaxy. M33 is a spectacular spiral galaxy that is relatively nearby.

Once you get the hang of it, you can download data for other objects and make your own images! Go to http://rbseu.uaa.alaska.edu/projects/imagemaking/ to get the data. Once you make an image post it on social media (Instagram, Facebook, Twitter, etc.) with the hashtag #ColortheUniverse so others can see your work!

Requirements

To participate in this tutorial, you will need the following software:

* The ESA/ESO/NASA *FITS Liberator 3*
* *Adobe Photoshop* or *Photoshop Elements*

If you have problems please feel free to contact the author at the email address above.

Description of the Data

The datasets of M33 and other objects used in this tutorial were obtained with the WIYN 0.9-meter telescope on Kitt Peak, which is located about 40 miles west of Tucson, Arizona. The FITS files are 2048 x 2048 pixels, and about 16 Mb in size each. Datasets in the broadband UBVRI and narrowband Hα, [OIII], and [SII] filters are available. For this tutorial we will use only the B, V and Hα datasets for M33. But you are encouraged to play with the other datasets afterwards.

These datasets are provided to be used strictly for educational purposes. They may not be redistributed without permission. If you wish to use these files for other purposes please contact the author.

About the Software

This tutorial requires *Adobe® Photoshop®* (version 7.0 and later) or *Adobe*

Want to learn more about astronomers make color images of space? Get the inside scoop by reading "Coloring the Universe" by Travis A. Rector, Kimberly Arcand, and Megan Watzke. It contains over 300 beautiful images along with explanations of how they were made.

The WIYN 0.9-meter Telescope on Kitt Peak, Arizona.

Photoshop Elements (version 2.0 and later). Both run on the Macintosh (OS X) and PC (Microsoft Windows) platforms. In this tutorial *Photoshop CS6* will be used, but it is very similar for *Photoshop Elements*.

This tutorial also requires the ESA/ESO/NASA *FITS Liberator 3*. It is free and can be downloaded at *http://www.spacetelescope.org/projects/fits_liberator/* A more in-depth instruction manual on all of the capabilities of the FITS Liberator is also available at that URL.

Description of the Image-Making Process

When people see astronomical images they often ask: "Is that what it really looks like?" The answer is almost always no. This is because our telescopes are looking at objects that are usually too faint, and often too small, for our eyes to see. Furthermore, our telescopes can also "see" kinds of light that our eyes cannot, such as radio waves, infrared, ultraviolet, and X-rays. In a sense, telescopes give us "super human" vision. Indeed, that's why we build them!

It is important to note that telescopes work differently than a traditional camera. The instruments on our telescopes are designed to detect and precisely measure light. We must then take the data that comes from the telescope and translate it into an image that our eyes can see, and our minds can understand.

Astronomical images are now made in a different way than they were even just twenty years ago. Instead of film or photographic plates we use electronic instruments, such as CCD ("charge-coupled device") cameras. In addition to their better sensitivity, these electronic devices also produce data that can be analyzed on a computer. Finally, thanks to the tremendous leaps in computing power and in image-processing software, it is now possible to produce high-quality color images of astronomical objects in a purely digital form.

One particular advantage of image-processing software, such as *Photoshop*, is that they use a "layering metaphor" for assembling images. In this system, individual images, which are stored as separate layers, may be combined to form a single image. Before this, color images were assembled from only three grayscale images. And each grayscale image could only be assigned to the "channel" colors of red, green, or blue. With the layering metaphor, it is possible to combine any number of images. And each image may be assigned any color you like (e.g., orange, yellow, or cyan). The layering technique has been used to produce astronomical images with as many as thirteen different images! Each grayscale image is produced from a different dataset, each of which shows different details in the astronomical object. These images are therefore richer in color and detail. This tutorial explains how its done.

The steps followed to produce a color image can be summarized as:

- Convert each FITS file into a grayscale TIFF image.
- Import each grayscale TIFF image into *Photoshop* as layers.
- Rescale each layer to maximize the contrast and detail.
- Assign a different color to each layer.
- Fine tune the color balance of the image.
- Align the image layers and remove any cosmetic defects.

Each step is described in detail below. Note: In this document an "▣" icon appears when a computer command is described.
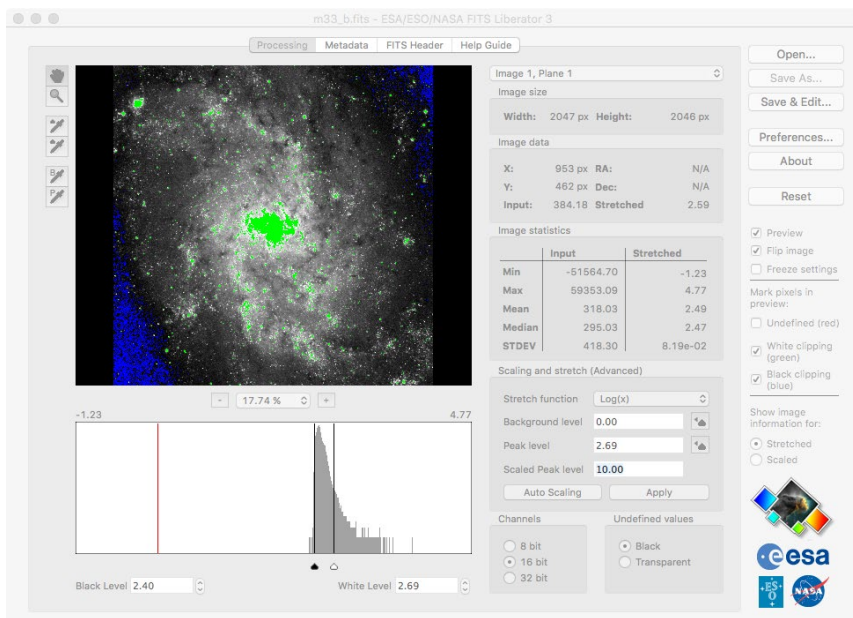
Note!

Many of the steps described in this process are subjective. They are based upon the color calibration of the author's computer display, and his personal aesthetics. If your final image does not look pleasing, it is either because you did not follow a step correctly, your computer's monitor is not properly calibrated (many monitors are too dark), or you do not share the author's excellent aesthetic palette.

Nomenclature:

FITS stands for **F**lexible **I**mage **T**ransport **S**ystem. It is the standard format for storing astronomical data. Note that FITS files are not technically images. Instead, they contain the data that can be converted into an image.

Converting the M33 Datasets with FITS Liberator

The first image we'll make is of the galaxy M33 with the B, V, and Hα FITS files. Adobe Photoshop cannot open FITS files because FITS is a data file format, not an image format. The FITS Liberator is a program that converts the pixels in a FITS file into pixels for an 8 or 16-bit grayscale image. In a FITS file the pixels may have any value they want, including negative values. In an 8-bit grayscale image, the pixels may only be one of 256 possible values. Thus, a mathematical function, often called a "transfer" or "stretch" function, must be used to convert the data pixel values in the FITS files into grayscale image pixel values.

- Launch *FITS Liberator 3*.
- Convert the B-filter file of M33 with FITS Liberator:
  - Click on the **Open...** button and select 'm33_b.fits' data file. A window should appear that looks similar to the one shown above.
  - Change the stretch function to 'Log(x)'.
  - On the right side of the image make sure that the 'White clipping (green),' and 'Black clipping (blue)' check boxes are selected.
  - You should now see blue and green pixels on the image. Move the black level slider (under the histogram) until most of the blue pixels in the image are gone. The Black Level (under the histogram) should be at, or close to, a value of 2.35.
  - Move the white level slider (also under the histogram) all the way to the right so that the White Level (shown at the bottom) is 4.76. Most of the green pixels in the image should now be gone.
  - Click the 'Auto Scaling' button. The image above should now appear nearly black. To increase the contrast in the faint parts of the image, change the 'Scaled Peak level' to 1000 and hit return (do not click on the Auto Scaling button again because it will reset the scaled peak level back to 10). The image should be brighter, the Black Level should be 0.00 and the White Level should be 3.00. The window should look like

Why 256?

Why only show 256 shades of gray? Each pixel only contains 8 bits of data. Since $2^8 = 256$, those 8 bits translate to 256 possible shades. In a 16-bit image, $65,536$ (2^{16}) values are possible. But computers can't display more than 256 shades, and our eyes can't see much more than that either.

Decoding file names

The FITS filenames consist of the name of the object, an underscore, and then the filter name. For example, the **m33_b** FITS file is data for M33 when it was through the B filter. The B filter only lets blue light pass through.

Nomenclature:

Clipping refers to the pixel values that are outside the range between the black and white points.

Pixels below the black point (shown in blue) will be set to a pure black. And pixels above the white point (shown in green) will be set to a pure white. These pixels are said to be 'clipped' because you will not be able to see any detail in these regions.

Make sure the black and white points are set so that there are very few blue or green pixels in the image.

what is shown below.

- If you are using *Photoshop 7.0* or *Photoshop Elements*, change the Channels (bottom center) to 8 bit. Otherwise leave it as 16 bit.
- Click on the **Save As...** button' and save the image as 'm33_b.tiff'.
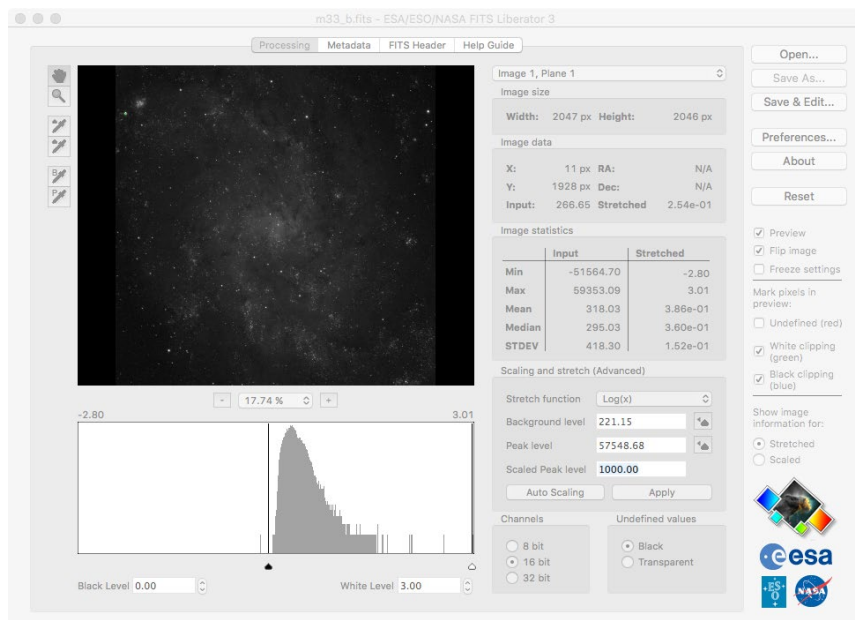
Scaled Peak Level

The scaled peak level adjusts the contrast in the image. A small scaled peak level means there is high contrast (better detail) in the bright parts of the image, but poorer contrast (less detail) in the faint parts of the image. A large scaled peak level does just the opposite. Thus, the scaled peak level should be adjusted to best show the detail in the bright and faint parts of the image.

Now it is time to import the other datasets and copy them into the main image file. We will next do the V-band dataset:

- 🖳 Convert the V-filter file of M33 with FITS Liberator:
- Click on the **Open...** button and select the 'm33_v.fits' data file.
- Make sure the stretch function is set to 'Log(x)'.
- Move the black level slider so that the Black Level is 2.54. Most of the blue pixels in the image should now be gone.
- Move the white level slider so that the White Level is 5.38. Most of the green pixels in the image should now be gone.
- Click the 'Auto Scaling' button. The image above should now appear nearly black. To get the same contrast as the B layer, change the 'Scaled Peak level' to 1000 and hit return (remember, do not click the Auto Scaling button again).
- If you are using *Photoshop 7.0* or *Photoshop Elements*, change the Channels (bottom center) to 8 bit. Otherwise leave it as 16 bit.
- Click on the **Save As...** button' and save the image as 'm33_v.tiff'.

- 🖳 Convert the Hα-filter file of M33 with FITS Liberator:
- Click on the **Open...** button and select the 'm33_ha.fits' data file.
- Make sure the stretch function is set to 'Log(x)'.
- Move the black level slider so that the Black Level is 1.47. Most of the blue pixels in the image should now be gone.

The V Filter

The **m33_v** FITS file is M33 in the V filter. The V filter only lets green light pass through. The 'V' stands for "visible."

The Hα Filter

The **m33_ha** FITS file is M33 in the Hα filter. Pronounced "H-alpha", this is a special "narrowband" filter that only passes a special color of red light produced by warm hydrogen gas. It is commonly used when studying objects that contain hydrogen gas, such as nebulae and galaxies.

- Move the white level slider so that the White Level is 3.70. Most of the green pixels in the image should now be gone.
- Click the 'Auto Scaling' button. Change the 'Scaled Peak level' to 1000 and hit return (do not click the Auto Scaling button again).
- If you are using *Photoshop 7.0* or *Photoshop Elements*, change the Channels (bottom center) to 8 bit. Otherwise leave it as 16 bit.
- Click on the **Save As...** button' and save the image as 'm33_ha.tiff'.

Preparing the Color Image of M33 in Photoshop

You should now have three grayscale TIFF files. The next step is to open them in *Photoshop* and transfer them to a single image file. Once we are done this will be the color image:

- Launch *Adobe Photoshop*.
- Prepare the main image file:
  - Choose **File/Open...** and select the 'm33_b.tiff' grayscale image.
  - If it is not visible already, choose **Window/Layers** to make the layers window visible. A single layer should be present, titled 'background.' It should look similar to what's shown below:
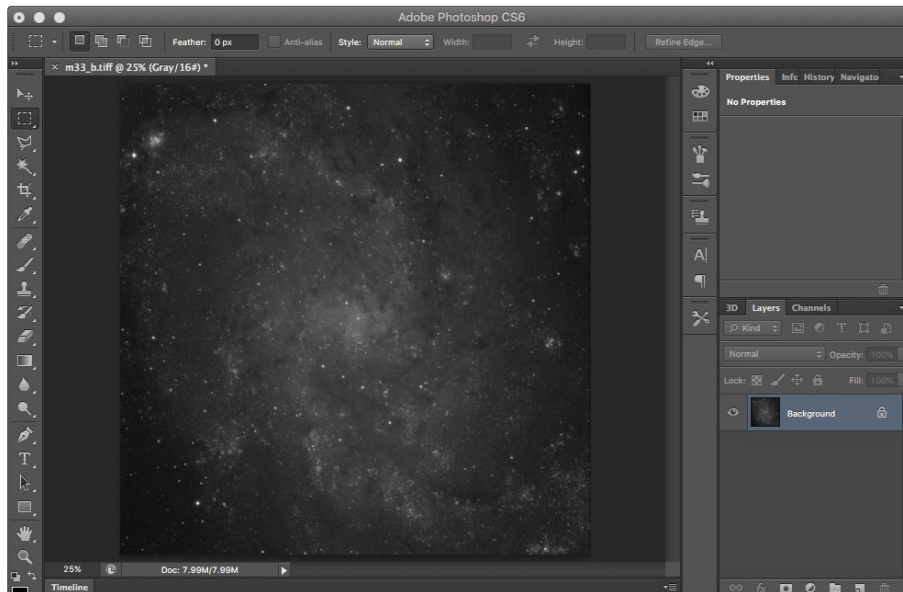
- In the layers window on the right side, double click on the background layer. A dialog box titled 'New Layer' will appear like the one shown below. Rename the layer to 'B log(1000)'. This will be useful later for keeping track of which layer is which.
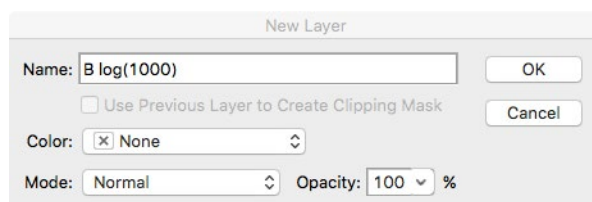
Warning!

On the right side of the *Photoshop* window are two smaller windows we will use. In the top half you should see the properties window. In the bottom half you should see the layers window. Make sure both the properties and layers windows are visible.

Note!

We name the layers to give the name of the filter used as well as the stretch function used in FITS liberator. In this case, ' log(1000)' indicates that we used a logarithmic stretch function with a scaled peak value of 1000.

- Currently *Photoshop* considers this image to be grayscale, and therefore disables the functions related to color. Choose **Image/Mode/RGB Color** to convert the image into a color image. Note: This won't change the appearance of the image. It simply prepares the image so that it can be make into a color image later on.

- Now it is time to save the tutorial image as a separate file. Choose **File/ Save As...** to save the image as a Photoshop document. In the dialog box, choose the directory into which you want to save the image. Name the file 'm33_tutorial.psd.' Make sure the format is set to 'Photoshop' and the 'Layers' box is checked on. Don't worry about the other check boxes.

Loading the Other M33 TIFF Images

Now it is time to open the two other grayscale TIFF images and copy them into the main image file. We will start with the V-band dataset:

- ▣ Open the V-filter file of M33:
  - In *Photoshop*, choose **File/Open...** and open the file 'm33_v.tiff'.
  - Double click on the background layer in the layers window, rename the layer to 'V log(1000)'.

The V-band grayscale image now needs to be copied into the main image file:

- ▣ Choose **Layer/Duplicate Layer...** and a dialog box will appear like the one below. Change the destination to 'm33_tutorial.psd' and click 'OK'. Now the V-band image is copied into the main image file so we can get rid of this copy. Choose **File/Close** and *Photoshop* will ask you if you wish to save the image. Click on 'Don't Save.'
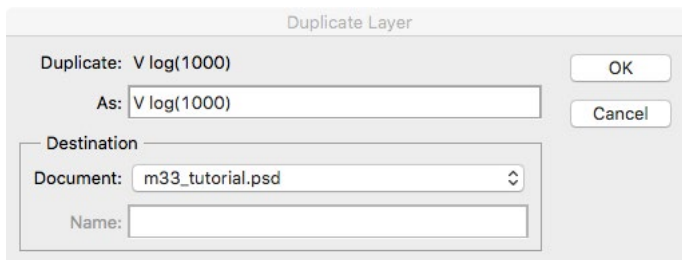
The B-band and V-band grayscale images are now loaded into the main image file, each as a separate layer. Finally, import the Hα image and duplicate it into the main image file:

- ▣ Import the Hα-filter file of M33 with FITS Liberator:
  - In *Photoshop*, choose **File/Open...** and open the file 'm33_ha.tiff'
  - In the layers window, rename the layer to 'ha log(1000)'.
  - Choose **Layer/Duplicate Layer...** and a dialog box will appear. Change the destination to 'm33_tutorial.psd' and click 'OK'. Now that the Hα-band image is copied into the main image file we can get rid of it. Choose **File/Close** and *Photoshop* will ask you if you wish to save the image. Click on 'Don't Save.'

Nomenclature:

Contrast is a measure of how well differences in brightness can be seen. In a high-contrast image, even small differences in brightness can be seen.

Dynamic range is the ratio of the intensity in the brightest region to the darkest region.

Contrast and dynamic range are at odds with each other. Overall, an image with high dynamic range will have a low contrast, and vice versa. The 'levels' and 'curves' tools are used to maximize the contrast in the interesting parts of the image, while maintaining a high dynamic range for the overall image.

All three grayscale image should now be in the main image file. The layers window should look as shown to the right. However, you will only see the image in the top layer. This is because the blending mode for each layer is set by default to 'Normal.' (The blending mode menu is the one near the top of the layers window.) For the light from the images in each layer to combine, the blending mode for each layer must be set to 'Screen':

- Select the 'ha log(1000)' layer by clicking on it. Change the blending mode from 'Normal' to 'Screen.' Change the modes for the other layers as well by selecting each layer and changing its blending mode. The opacity of each layer should be kept at 100%. (Note: Technically you don't need to change the blending mode of the bottom layer, but you might as well do it in case you change the order of the layers.)

The image will look much brighter now because the screen mode for each layer "adds" the intensity of the that layer to the overall image. You can see the effect of each layer on the overall image by turning on and off the visibility of each layer. This is done by clicking on the eyeball on the left side of each layer (in the layer window). When all of the layers are visible (i.e., when there is an eyeball visible next to each layer), the image should look as shown below:
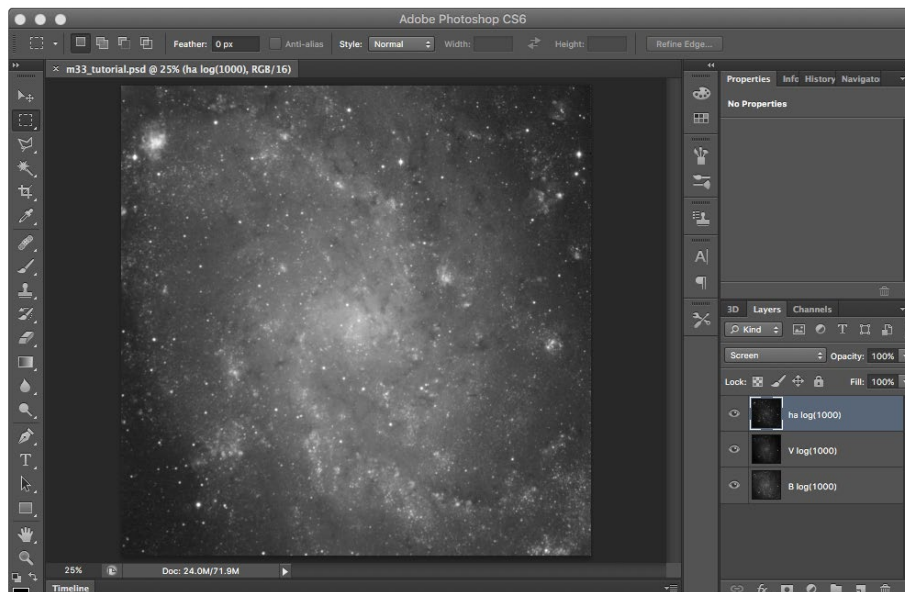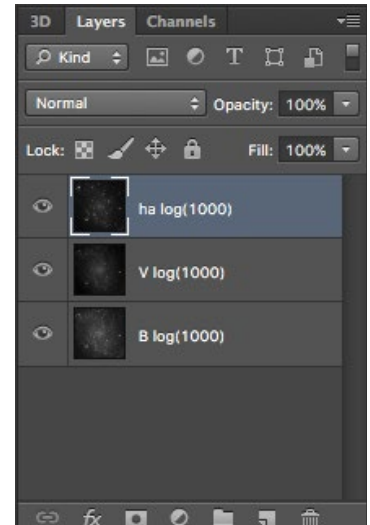

The layers window in *Photoshop* after the V-band and Hα images has been duplicated into the main image file.

If you have not done so recently, this is an excellent time to save the image.
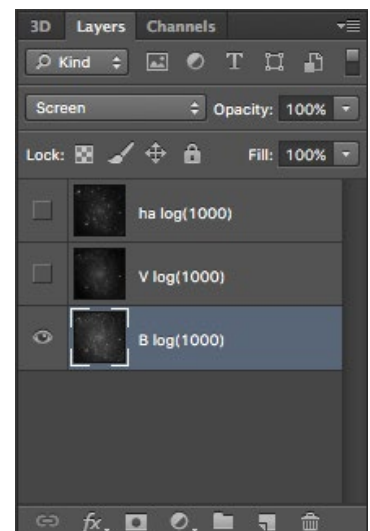
Rescaling and Colorizing Each Layer

Now that a grayscale image for each filter is loaded as a layer into the main image file, it is time to fine tune the intensity scaling for each layer so that we can best see the details in the faint *and* bright parts of the galaxy. This is best done by working with only one layer visible at a time:

- Rescale the intensity of the B-band layer:
  - Turn off the visibility of the V and Hα layers. There should only be an eyeball next to the B layer (as shown to the right).
  - Select the B layer by clicking it. It should be the one highlighted.
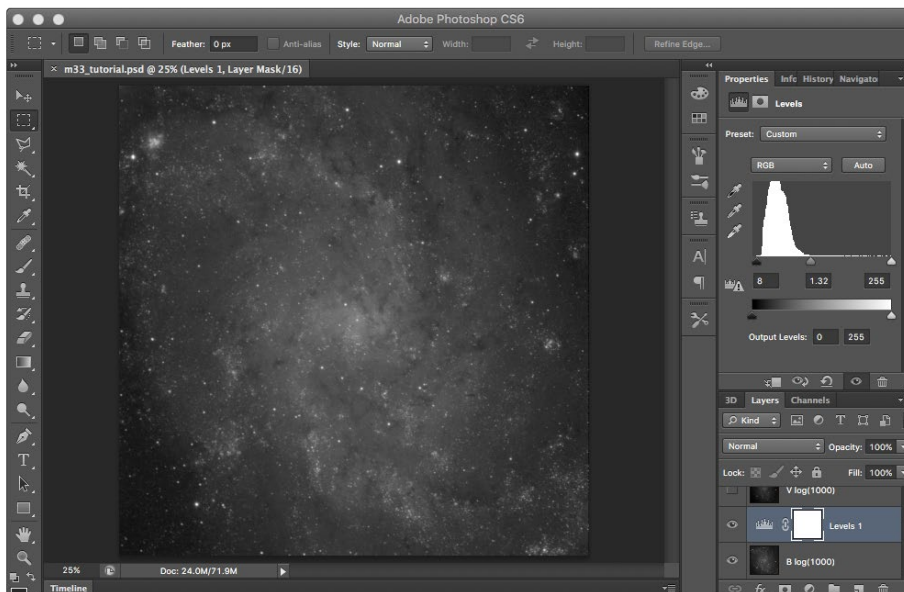 - Choose **Layer/New Adjustment Layer/Levels...** A 'New

The layers window in *Photoshop* after the visibility of the V-band and Hα images have been turned off. Note that there is an eyeball only next to the 'B log(1000)' layer.

Layer' dialog box will appear. Click 'OK' and a new layer will appear above the 'B log(1000)' layer. In the properties window (in the upper-right), a histogram will appear in the 'Input Levels' area of the window. Like in the FITS Liberator, you can use the sliders underneath the histogram to move the black and white points. You'll also see a gray slider that adjusts the 'gamma' correction.

- Move the black slider a little to the right. As you move the slider you'll notice the image gets darker. Move it until the number below the black point is 8. This is done so that the image will be almost completely black in the darkest portions of the image, e.g., in the lower-left corner.

- Move the gray slider a little to the left. As you move the slider you'll notice the image gets a little brighter. Specifically, the contrast in the faint regions is increasing, and the contrast in the dark regions is decreasing. Move the gray slider until he number below the gray point (also known as the gamma correction) should be about 1.32. This is done to improve the contrast in the center of the galaxy.

- Do not move the white slider. The white point should remain at 255. And don't change the Output Levels. The window should look as shown:

This is the histogram as seen in the properties window in *Photoshop.* Like FITS Liberator, you use this to control the brightness and contrast of the image.
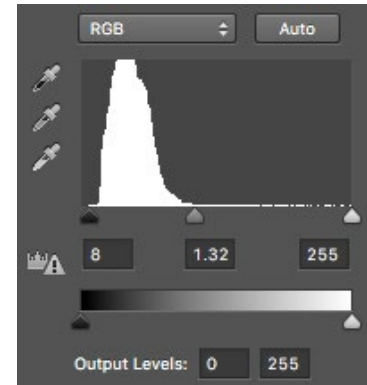
This new layer is called an 'adjustment layer.' It does not consist of an image; rather, it adjusts the appearance of the layers below it. You can see the effect of the adjustment layer by toggling the visibility of the layer (i.e., clicking on and off the eyeball for the adjustment layer.) The effect of the adjustment layer is that it improves the contrast in the center of the galaxy while keeping the outer edges of the galaxy from getting too bright.

An adjustment layer will affect *all* of the layers below it unless it is "grouped" to a single layer. The 'Levels 1' adjustment layer must therefore be grouped to the B-band layer so it only adjusts it. (Note: For the B-band image layer this is not a problem because there are no other layers below it, but it will be an issue for the other image layers.)

Note!
In other versions of *Photoshop* and in *Photoshop Elements* some of the settings (e.g., input levels) may be in a different location.

- Select the 'Levels 1' adjustment layer by clicking on it. Choose **Layer/ Create Clipping Mask**. The adjustment layer will indent; and an arrow will point down to the B-band image layer.

Finally, we will assign a color to the layer. This is done with the 'Hue/Saturation' adjustment layer:

🗔 Assign a blue color to the B-band layer:

- Select the 'Levels' layer above the B-band layer by clicking it. It should be the one highlighted.

- Choose **Layer/New Adjustment Layer/Hue/Saturation...** A 'New Layer; dialog box will appear. Click 'OK' and a new layer will appear above the 'Levels 1' adjustment layer. In the properties window there will be three sliders for hue, saturation, and lightness.

- Before moving any of the sliders click on the 'Colorize' checkbox in the lower-right corner of the properties window. The image will go red.

- Once the colorize checkbox is selected, the hue slider will determine what color the layer will be. The numbers correspond to an angle on the color wheel between 0° and 360° (see the figure to the right). Since this is the blue filter, set the hue to 240. The image will turn blue.

- Set the saturation to 100 and the lightness to -50. This will make the image a deep, dark blue. The window should look as shown below:

The angles around the color wheel correspond to hue values.
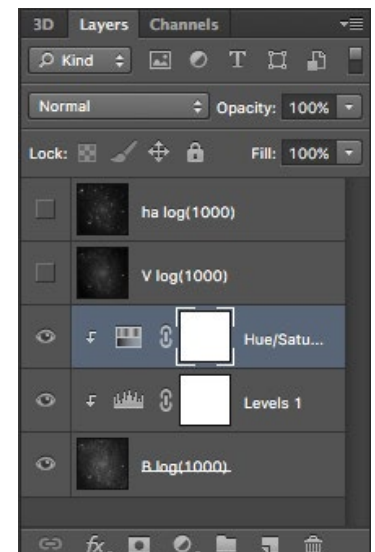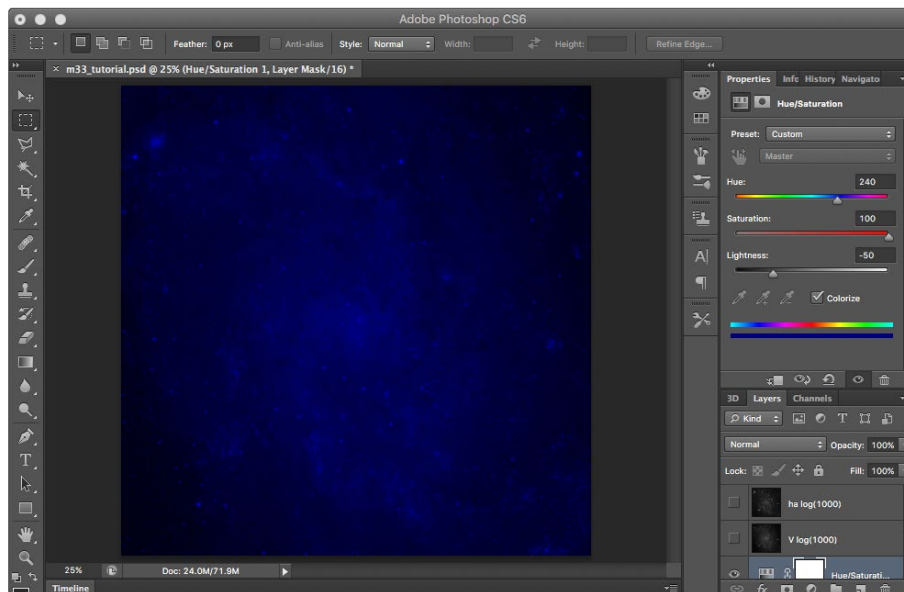
- A new adjustment layer titled 'Hue/Saturation 1' should now be above the 'Levels 1' layer.

- Select the 'Hue/Saturation 1' adjustment layer by clicking on it. Choose **Layer/Create Clipping Mask**. The adjustment layer will indent; and an arrow will point down to the 'Levels 1' image layer. The layers window should look as shown on the right.

The layers window in *Photoshop* after the B-band layer has been rescaled and colorized. The Hα and V layers have not yet been rescaled and colorized.

Since the 'Levels 1' and 'Hue/Saturation 1' adjustment layers are grouped to the B-band layer they will only adjust that layer. The layers window should look as shown to the right.

Now its time to rescale and colorize the V-band and Hα layers by following the same steps as described above for the B-band layer:
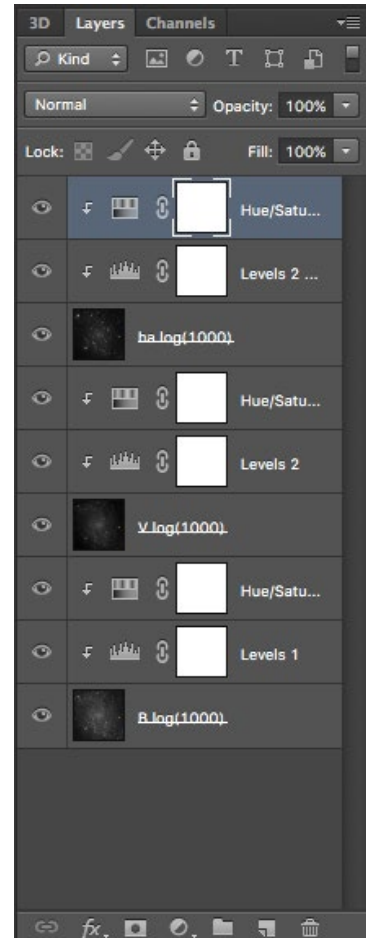
🖳 Rescale and colorize the V-band layer:

- Turn off the visibility of the B-band layer. Select the V-band layer and turn on its visibility.

- Choose **Layer/New Adjustment Layer/Levels...** A 'New Layer; dialog box will appear. Click 'OK' and the levels window will appear. To increase the contrast in the faint parts of the galaxy, set the black point to 0 and the gray point to 1.23. Do not move the white point. Click 'OK' and then group the levels adjustment layer by choosing **Layer/Create Clipping Mask**.

- Choose **Layer/New Adjustment Layer/Hue/Saturation...** Click on the 'Colorize' checkbox. Since the V-band filter is green, set the hue to 120. Set the saturation to 100 and the lightness to -50. This will make the image a dark, deep green. Click 'OK' and then group the hue/saturation adjustment layer by choosing **Layer/Create Clipping Mask**.

🖳 Rescale and colorize the Hα layer:

- Turn off the visibility of the V-band layer. Select the Hα layer and turn on its visibility.

- Choose **Layer/New Adjustment Layer/Levels...** A 'New Layer; dialog box will appear. Click 'OK' and the levels window will appear. Set the black point to 0 and the gray point to 1.05. Do not move the white point. Click 'OK' and then group the levels adjustment layer by choosing **Layer/Create Clipping Mask**.

- Choose **Layer/New Adjustment Layer/Hue/Saturation...** Click on the 'Colorize' checkbox. Since the Hα filter is red, set the hue to 0. As before, set the saturation to 100 and the lightness to -50. This will make the image a dark, deep red. Click 'OK' and then group the hue/saturation adjustment layer by choosing **Layer/Create Clipping Mask**.

Each image has now been rescaled and colorized. Make sure that each adjustment layer is grouped to the image layer below it. To see how the overall image looks turn on the visibility of the B-band and V-band layers. The layers window should look as shown on the right; and the image should look as shown below:

The layers window in *Photoshop* after all three layers have been rescaled and colorized.
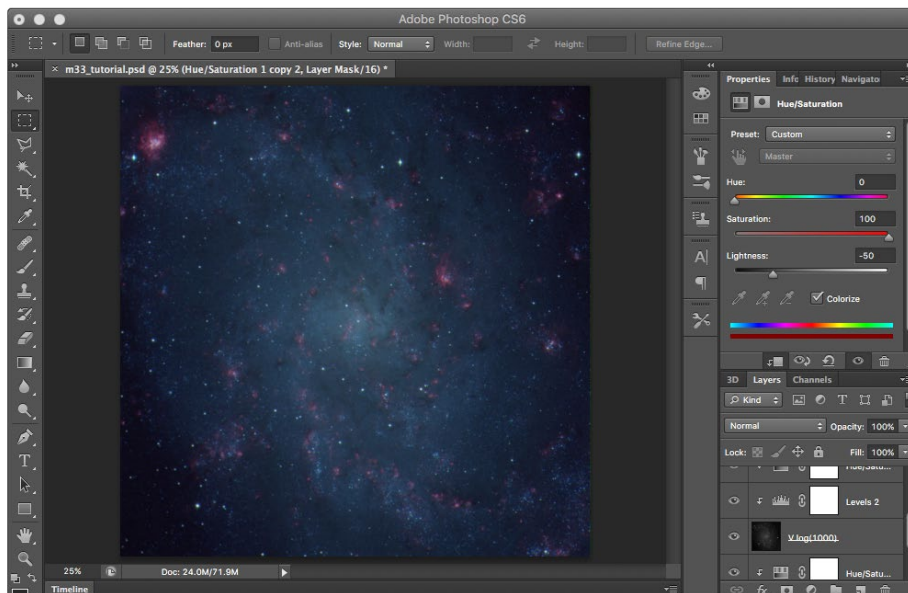
Its not bad, but the galaxy has too much cyan. This is because the B-band and V-band filters primarily show the stars in the galaxy, whereas the Hα filter primarily shows the warm hydrogen gas in the galaxy (where stars are forming). Thus the stars will look cyan, which is a mix of blue and green. Cyan is on the opposite side of the color wheel as red. Thus, to bring the image better into balance, we need to either decrease the cyan or increase the red. This can be done by changing the setting in the levels and hue/saturation adjustment layers. There are so many settings that can be changed, it ca be confusing. How to do this is more easily understood if you think in terms of the color wheel (again shown on the right). To start we'll try by adjusting the color assigments to each layer:


The angles around the color wheel correspond to hue values.

- ▣ Adjust the color assignments to the B, V and Hα layers:
  - Leave the visibility of all of the layers on as you do this so you can see how changes affect the overall image.
  - Click on the levels adjustment layer for the Hα image. To brighten the Hα regions move the gray point to 1.95.
  - The background is now too red. To darken the background move the black point from 0 to 10.

The image should now look close to what is shown below:
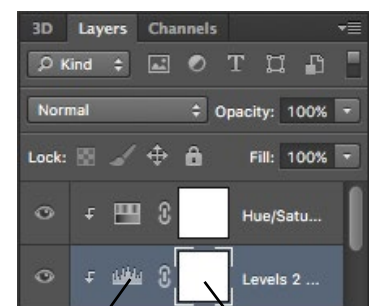
Layer thumbnail   Layer mask thumbnail

Caution!

If you double-click on the layer mask thumbnail (the white square to the right of the layer thumbnail) a 'Layer Mask Display Options' window will appear. If this occurs, click 'Cancel' and try again.

The colors are now more in balance. The image may also be improved by further adjusting the black and gray points (gamma correction) of the other level adjustment layers. Because this image uses only three datasets, the image can also be improved by using additional M33 datasets. These should be imported, rescaled and colorized in the same manner. Finally, there are many additional

tools that are available in Photoshop (e.g., the 'curves' tool) that enable the layers to be manipulated more precisely. For simplicity these methods and tools are not discussed here.

As always, this is an excellent time to save the image.

Fine Tuning the Image

The image is mostly done, but there are still several steps necessary to complete the image. One issue that has not yet been addressed is the alignment of the image layers. Because these images were taken with the same telescope and camera, and on the same night one after another, the images are already very closely aligned. However, if you zoom in on the image (say, to 500%, as shown on the right) you will notice that the stars are not perfectly aligned. To align the images use the 'move tool' to shift each image layer so that they are aligned with one another. (Note: Shifting the adjustment layers will have no effect):

> ▣ Select the Hα layer by clicking on it. Choose the 'move tool' and use the arrow keys to shift the layer until it is well aligned with the B-band layer. Now select the V-band layer and shift it as well so that it is aligned with the other two.

Zooming will also reveal that there are numerous dots and small streaks in the image. These are caused by cosmic rays that hit the CCD detector during each exposure. They are therefore in different locations in each filter image and therefore have a color that matches that filter; e.g., cosmic rays in the V-band image look green. In the case of this image, nearly all of the cosmic rays are in the V-band image.

These 'cosmic ray' specs and scratches can be fixed in a variety of ways in *Photoshop*. A simple option is to use one of the noise filters; e.g., the 'dust and scratches' filter. These can remove the cosmic rays, but they also blur the image. A more effective but time-consuming method is to use the cloning stamp and healing brush tools to remove the cosmic rays one by one. The user's manual for *Photoshop* explains how these tools are used.

Making an Image with Representational Color

Now we're going to make an image of the star-forming region M16. Also named the Eagle Nebula, M16 was made famous by an HST image known as the "Pillars of creation."

The image we created of M33 is often called a "true color" image because the color assigned to each grayscale image matches the actual color of the filter. That is, when you hold the B filter up to a bright, white light it looks blue. Likewise, the V filter looks green and the Hα filter looks red. Recall that when we made the image of M33 we made the B, V and Hα filters blue, green, and red respectively.

When we make an image of M16 we will use color in a different way, in a way often called "representational color" because the colors are intended to represent the science in the image. Using this method, we can see details in an object that might go unnoticed in a true-color image. For this image all of the filters we'll use are called "narrowband" filters. They do not show color and light in the same way as our eyes see it. The steps we'll follow will be essentially the same as what we did for the image of M33, so be sure to do that tutorial first.
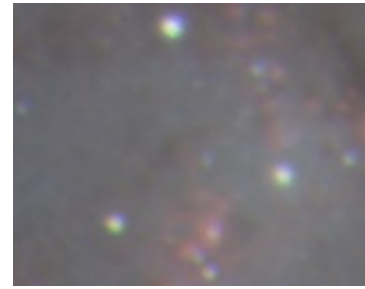
Zooming into the image to 500% shows that the stars are not aligned. Use the 'move tool' in *Photoshop* to align the image layers.

Narrowband Filters

A narrowband filter only allows a specific color of light to pass through it. Recall that the Hα filter is a special narrowband filter that only passes a specific color of red light produced by warm hydrogen gas. Likewise, the [OIII] filter (pronounced "Oxygen 3") passes a specific color of green light from hot oxygen gas. And the [SII] filter (pronounced "Sulphur 2") passes a specific color of red produced by hot sulphur gas.

Convert the Datasets with FITS Liberator

Like you did for M33, we will use the FITS Liberator program to convert the FITS datasets into grayscale TIFF files:

- ▣ Launch *FITS Liberator 3*.
- ▣ Convert the Hα filter file of M16 with FITS Liberator:
  - Click on the **Open...** button and select 'm16_ha.fits' data file. A window should appear that looks similar to the one in the M33 tutorial.
  - Change the stretch function to 'Log(x)'.
  - On the right side of the image make sure that the 'White clipping (green),' and 'Black clipping (blue)' check boxes are selected.
  - You should now see blue and green pixels on the image. Move the black level slider (under the histogram) until most of the blue pixels in the image are gone. The Black Level (under the histogram) should be at, or close to, a value of 2.55.
  - Move the white level slider (also under the histogram) all the way to the right so that the White Level (shown at the bottom) is 4.83. Most of the green pixels in the image should now be gone.
  - Click the 'Auto Scaling' button. The image above should now appear nearly black. To increase the contrast in the faint parts of the image, change the 'Scaled Peak level' to 1000 and hit return (do not click on the Auto Scaling button again because it will reset the scaled peak level back to 10). The image should be brighter, the Black Level should be 0.00 and the White Level should be 3.00.
  - If you are using *Photoshop 7.0* or *Photoshop Elements*, change the Channels (bottom center) to 8 bit. Otherwise leave it as 16 bit.
  - Click on the **Save As...** button' and save the image as 'm16_ha.tiff.'

- ▣ Convert the [OIII] filter file of M16 with FITS Liberator:
  - Follow the same steps as above for the 'm16_o3.fits' data file. Set the Black Level to 2.19 and the White Level to 4.81.
  - Click on the **Save As...** button' and save the image as 'm16_o3.tiff.'

- ▣ Convert the [SII] filter file of M16 with FITS Liberator:
  - Follow the same steps as above for the 'm16_s2.fits' data file. Set the Black Level to 2.36 and the White Level to 4.82.
  - Click on the **Save As...** button' and save the image as 'm16_s2.tiff.'

Preparing the Color Image of M16 in Photoshop

You should now have three grayscale TIFF files. The next step is to open them in *Photoshop* and transfer them to a single image file:

- ▣ Launch *Adobe Photoshop*.
- ▣ Prepare the main image file:
  - Choose **File/Open...** and select the 'm16_ha.tiff' grayscale image.

- If it is not visible already, choose **Window/Layers** to make the layers window visible. A single layer should be present, titled 'background.'

- In the layers window on the right side, double click on the background layer. Rename the layer to 'ha log(1000)'.

- Choose **Image/Mode/RGB Color** to convert the image into a color image. Note that this will not change the appearance of the image.

- Choose **File/Save As...** to save the image as a Photoshop document. Name the file 'm16_tutorial.psd.' Make sure the format is set to 'Photoshop' and the 'Layers' box is checked on.

Loading the Other M16 TIFF Images

Now it is time to open the two other grayscale TIFF images and copy them into the main image file. We will start with the [OIII] dataset:

- Open the [OIII]-filter file of M16:

  - In *Photoshop*, choose **File/Open...** and open the file 'm16_o3.tiff'.

  - Double click on the background layer in the layers window, rename the layer to 'o3 log(1000)'.

This image now needs to be copied into the main image file:

- Choose **Layer/Duplicate Layer...** and a dialog box will appear like the one below. Change the destination to 'm16_tutorial.psd' and click 'OK'. Now the [OIII] image is copied into the main image file so we can get rid of this copy. Choose **File/Close** and *Photoshop* will ask you if you wish to save the image. Click on 'Don't Save.'

Repeat the steps above for the [SII] file. Now change the blending mode for each layer to 'Screen':

- Select the 'ha log(1000)' layer and change the blending mode from 'Normal' to 'Screen.' Change the modes for the other layers as well. The opacity of each layer should be kept at 100%.

If you have not done so recently, this is an excellent time to save the image.

Rescaling and Colorizing Each Layer

Now we'll fine tune the intensity scaling for each layer so that we can best see the details in the faint *and* bright parts of the nebula:

- Rescale the intensity of the Hα layer:
  - Turn off the visibility of the [OIII] and [SII] layers. There should only be an eyeball next to the Hα layer.
  - Select the Hα layer by clicking it.
  - Choose **Layer/New Adjustment Layer/Levels...** A 'New Layer' dialog box will appear. Click 'OK' and a new layer will appear above the 'ha log(1000)' layer. In the properties window (in the upper-right), a histogram will appear in the 'Input Levels' area of the window. Like in the FITS Liberator, you can use the sliders underneath the histogram to move the black and white points. You'll also see a gray slider

that adjusts the 'gamma' correction.

- Move the black slider to the right until the number below the black point is 12. Move the gray slider a little to the right 0.78. And the white point should remain at 255. Don't change the Output Levels. The window should look as shown to the right.

- Select the 'Levels 1' adjustment layer by clicking on it. Choose **Layer/ Create Clipping Mask**. The adjustment layer will indent; and an arrow will point down to the Hα-band image layer.

The histogram for the Hα layer. Notice that the black point is on the left edge of the histogram, the gray point is on the right edge, and the white point is all the way to the right. You'll set the black and gray points in a similar way for the other layers.

Finally, we will assign a color to the Hα layer. Recall that for M33 we made the Hα layer red because that is the true color of Hα. However, [SII] is also red. In fact, to our eyes Hα and [SII] are indistinguishable shades of red. By using narrowband filters our cameras can tell the difference between them. In this image we will make the Hα layer green because we are going to use red for [SII]. By using different colors for Hα and [SII] we will be able to see the difference between the two.

We will make the [SII] red because it is a slighly lower energy of light than Hα. Finally, we will assign blue to the [OIII] filter because it has the highest energy of the three. Assigning colors based upon their energy is called "chromatic ordering," and is a type of representational color.

🖳 Assign a green color to the Hα layer:
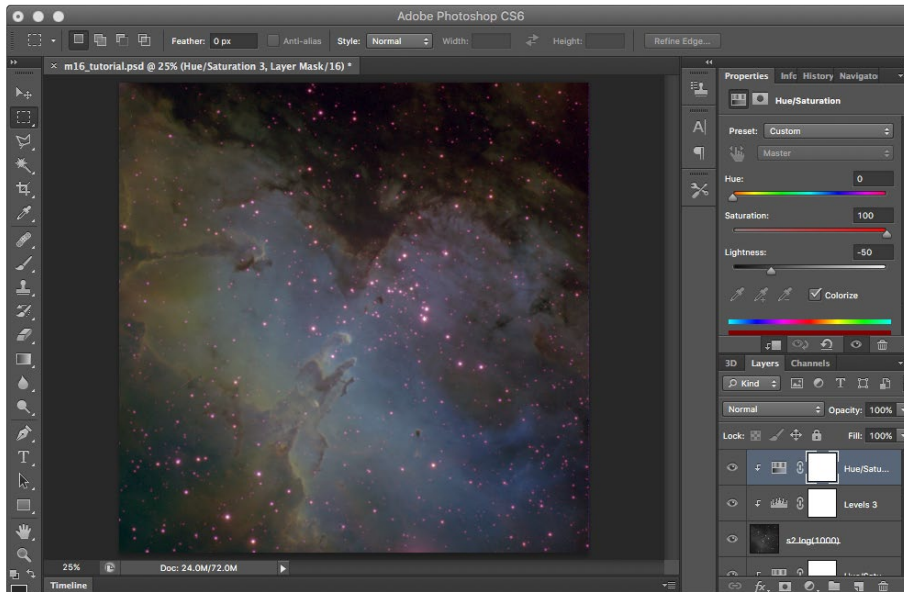
- Select the 'Levels' layer above the Hα layer by clicking it. It should be the one highlighted.

- Choose **Layer/New Adjustment Layer/Hue/Saturation...** A 'New Layer; dialog box will appear. Click 'OK' and a new layer will appear above the 'Levels 1' adjustment layer.

- Click on the 'Colorize' checkbox in the lower-right corner of the properties window. The image will go red.

- Set the hue to 120. The image will turn green.

- Set the saturation to 100 and the lightness to -50. This will make the image a deep, dark green.

- Choose **Layer/Create Clipping Mask** to group the adjustment to the image layer below it.

Since the 'Levels 1' and 'Hue/Saturation 1' adjustment layers are grouped to the Hα layer they will only adjust that layer. Now its time to rescale and colorize the [OIII] and [SII] images by following the same steps as above. Make the [OIII] layer blue by setting its hue equal to 240. And make the [SII] layer red by setting its hue equal to 0.

Each image should now be rescaled and colorized. Make sure that each adjustment layer is grouped to the image layer below it. To see how the overall image looks turn on the visibility of all the layers (i.e., make sure the eyeballs are on next to all of the layers.) The image should look as shown on the next page:
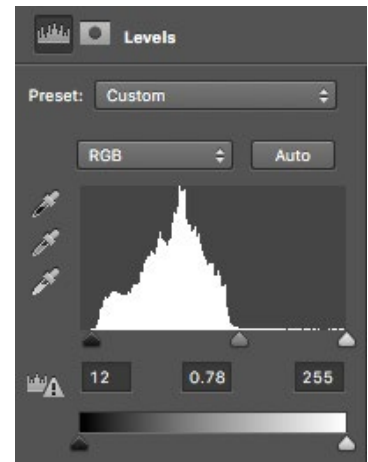
A New Tool!

If you followed all of the steps correctly, your image should look similar to the one shown above. This looks nice but needs improvement. Specifically, we wish to brighten the image in the center. This will also increase the contrast. To do this we're going to use a new tool, called the 'curves' tool. It is similar to the 'levels' tool but gives you greater control over adjustments to the brightness and contrast:

- Use curves to adjust the brightness/contrast of the entire image:
  - Make sure all of the layers are visible. There should be an eyeball next to each layer.
  - Select the topmost layer by clicking it.
  - Choose **Layer/New Adjustment Layer/Curves…** A 'New Layer' dialog box will appear. Click 'OK' and a new layer will appear on top of all of the other layers. In the properties window (in the upper-right), a window will appear that looks like the window to the upper right. Like the curves tool this window is a histogram. You will see a white line that runs diagonally from the lower-left corner to the upper-right corner.
  - Click on the white line somewhere along the lower-left part of the line. A box will appear on the line. This is called an 'anchor point.' Below the histogram change the Input to 74 and the Output to 76.
  - Click on the white line again, this time along the upper-right part of the line. Another box will appear on the line. Below the histogram change the Input to 131 and the Output to 185. The white line should now look like what's shown in the window on the lower right.

The curves tool is, at first, counter-intuitive. But it is a powerful tool for adjusting the brightness and contrast in an image in more complex ways than the levels tool. The curves tool as it is set here, increases the brightness and contrast in the bright parts of the image while leaving the darker portion of the image unaffected. The image should now look as shown on the next page:
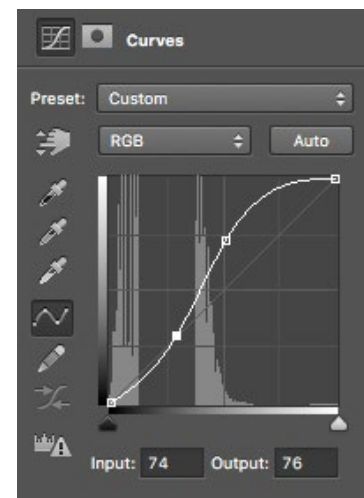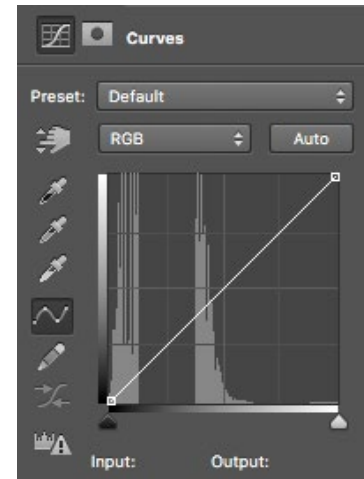
The curves adjustment tool before (top) and after (below) you add the two anchor points.
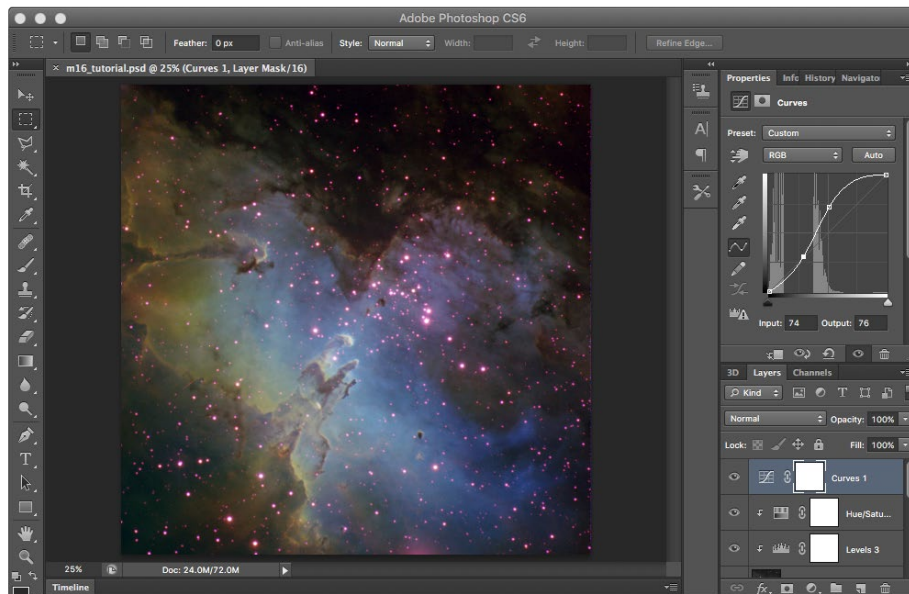
Notice that image is now brighter in the middle. The center of the image also has more contrast. Recall that contrast is a measure of how well you can see the difference between brighter and darker areas. Notice that you can now see the pillars at the center better.

As far as we are concerned for this tutorial, the image of M16 is done. Feel free to play with the curves layer to see how moving the anchor points affects the appearance of the image.

Practice, Practice!

Note that, in this tutorial, all of the steps are described as if it were an exact recipe, just like if you were baking a cake. In reality, the people who make these images are like master chefs: they know how to use a range of tools to make the images look they way they want, just like a good cook knows how to use different ingredients to make a meal taste just the way she or he wants. To keep things simple, in this tutorial we have introduced only a few of those tools.

Making images is indeed a lot like cooking: when you first try it you will follow steps that may not make much sense as you do them. But as you practice making new images you'll learn how the tools work and you'll get better. So keep practicing!

You can make more images with the data on the RBSE-U website (http://rbseu.uaa.alaska.edu/projects/imagemaking/). Be sure to post your images on social media with the hashtag #ColortheUniverse so people can see them.

Have fun!
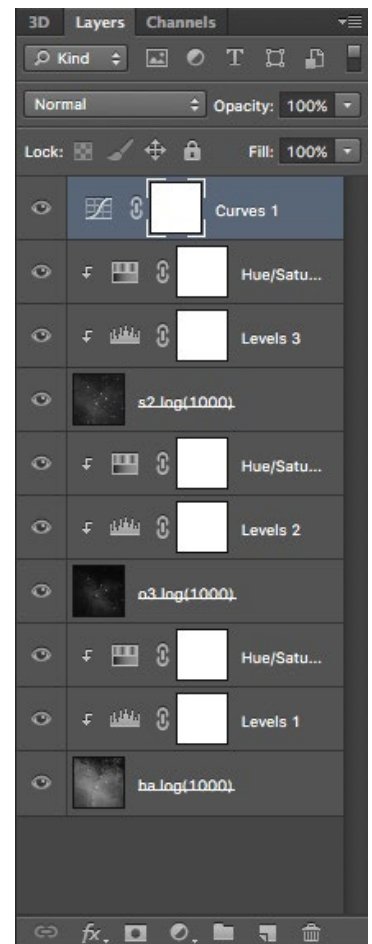
When the image is done the layers window should look as shown above. Note that the curves layer on top is *not* grouped to the layer below it. This way it affects *all* of the layers, which is what we want.