Astro-Imaging Processing Concepts & Processes

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Goals of this presentation:

- Introduce some useful concepts for understanding image processing.
- Introduce steps used in stacking astro-images.
- Introduce some “post processing”.
- Provide a starting point for asking questions.
- NOT COVERED - how to use specific software.

This presentation will cover-

- Review how imaging sensors in cameras work
- Review how color images are created
- The Bayer Filter Mosaic and demosaicing
- What are "darks", "flat fields" and "bias frames"?
- How to use darks, flats and bias frames.
- RAW, TIFF, FIT, JPG file formats.
- Color Depth (bits per color)
- What is signal?
- What is noise?
- What is signal to noise ratio?
- The Histogram
- Using the histogram in "post processing"
- Short list of resources

How do the imaging sensors in cameras work?

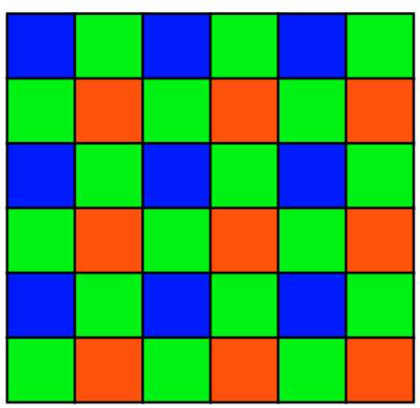
The **imaging sensors** in all modern digital cameras are electronic devices with a grid of tiny **photosensors**. Each photosensor corresponds to a **pixel** in the image.

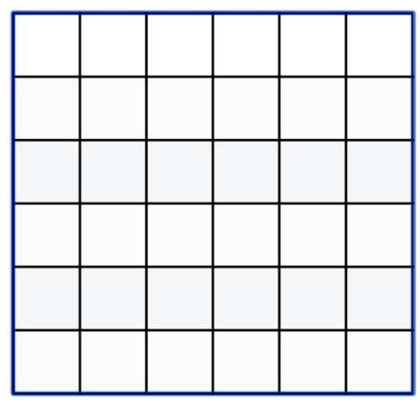
Photons hitting these photosensors are converted into electrons. The number of electrons in each photosensor is measured and converted into a digital number and saved in the camera's memory card.

Below are representations of color (with built-in color filters) and monochrome imaging sensors

The examples are 6x6 or 36 pixel sensors

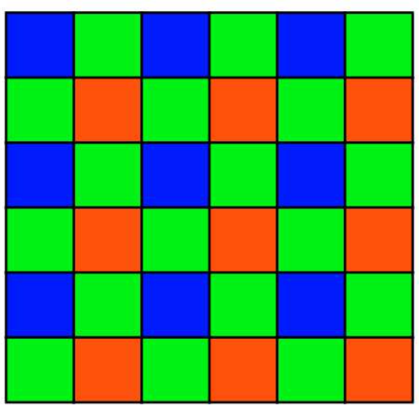
Typical imaging sensors have 10 - 24 million or more photosensors.

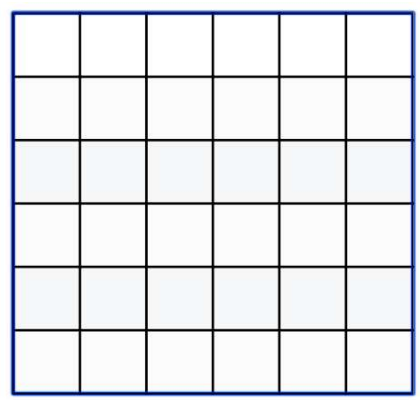




To make a **color image** we need **red, green and blue (RGB) color information**. For color sensors this is information is divided up among the photosensors by manufacturing them with tiny red, green and blue filters in front of the photosensors. This pattern of filters is called a **Bayer filter mosaic**. In astro-imaging circles, cameras with color imaging sensors are called **"one shot color" cameras**.

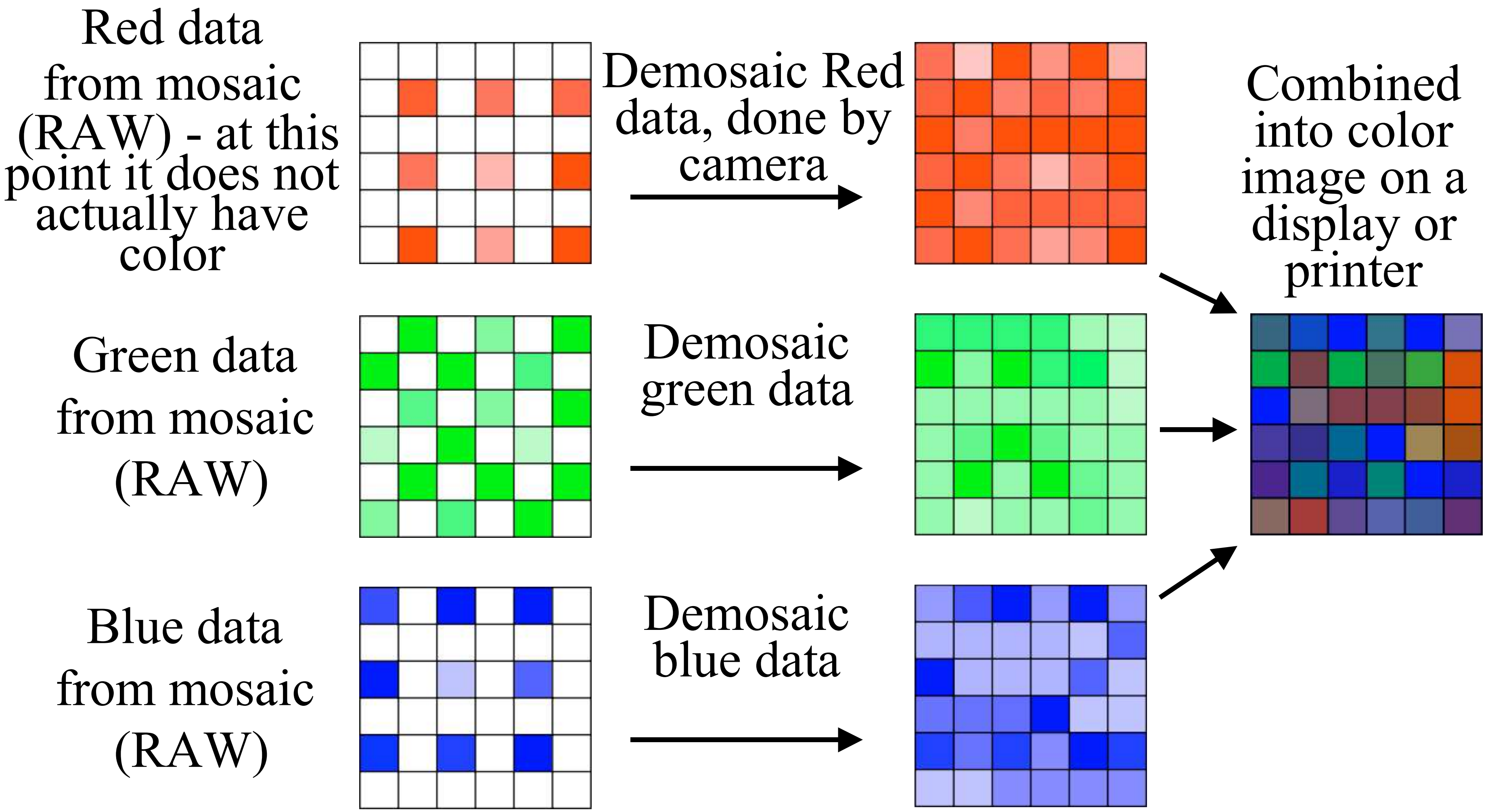
For **monochrome** sensors, **3 separate images are taken**. One with a red filter in front of the whole imaging sensor, one with a green filter and one with a blue filter. Most cameras used on space probes use this method and typically use other filters as well. **For astro-imaging a 4th image is typically taken with no filter.** This is called a **luminance (L) image** (we won't go into details here).





How a color image is created using data from a color sensor

With a color sensor, the red, green and blue data from the **Bayer filter mosaic** is **interpolated** to fill in the missing color data. This is called **demosaicing**, creating red, green and blue data for every pixel. Data is combined in a format that can be viewed on a computer as a color image.



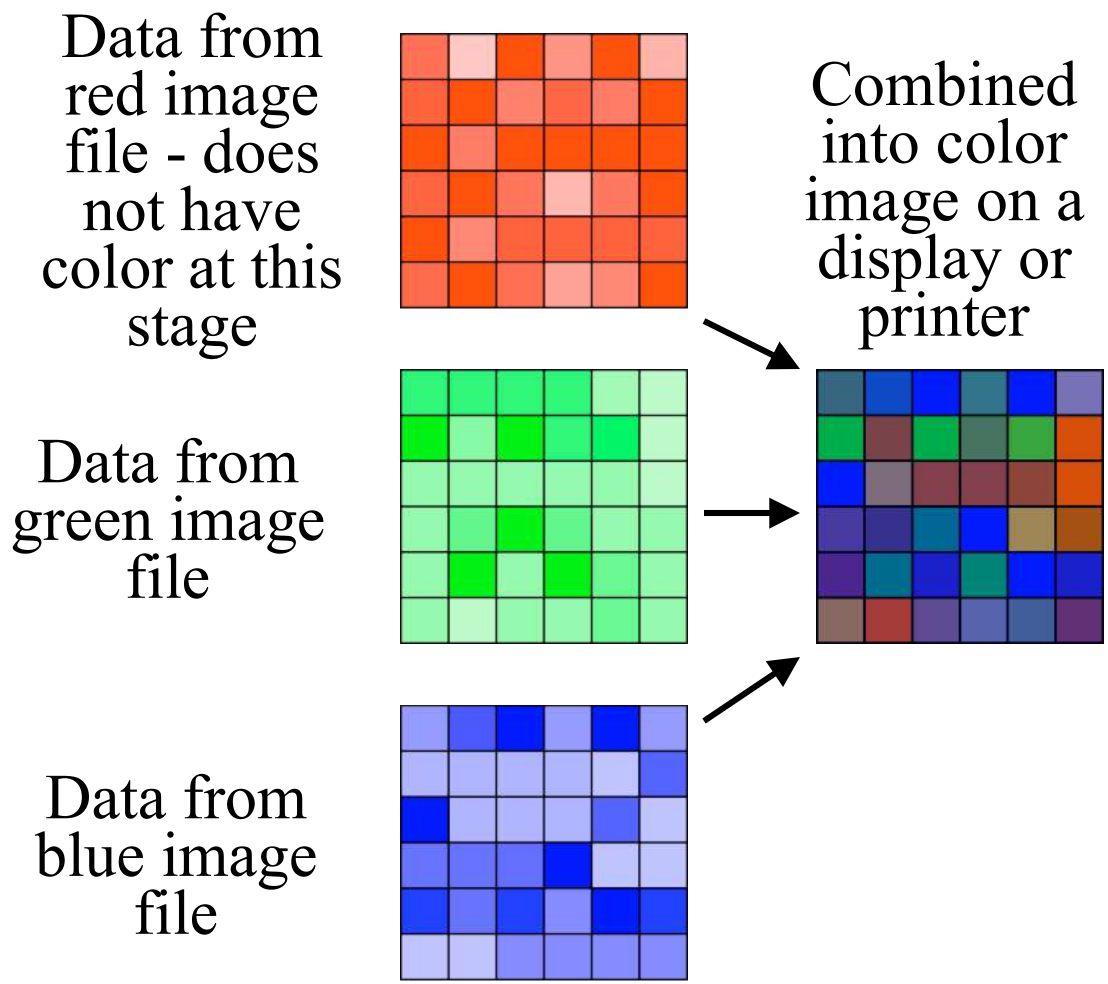
How a color image is created from a monochrome sensor

With a monochrome sensor, the red, green and blue data are saved in separate image files. Each file must be identified as R, G, or B data. Since there is R, G and B data for each pixel there is **no interpolation step.** The files are opened than combined and saved as 1 file.

The red, green and blue data are called **color channels**. Astro-images using monochrome sensors typically also have a **luminescence (L)** (brightness) channel.

Note on Color

The red, green and blue data exists only as numbers and therefore is **grayscale** data until it is viewed on a color monitor or printed out.



Terminology You will Encounter In Stacking Images

Lights, Light Images or Light Frames

These are the images taken of your subject.

Darks, Dark Images, Dark Frames (not required but highly recommended)

These are images taken with the exact same camera settings and exposure time as the Lights but with the front of the telescope covered so no light can get to the camera sensor. The temperature of the camera should as close a possible the same as when the Lights were taken. These are subtracted from the Light Frames.

Flats, Flat Field images or Flat Frames (not required but highly recommended)

These are images of an evenly illuminated field. This can be the twilight sky. It can be 2 layers of a white T-shirt covering the front of the telescope or camera lens illuminated with even lighting such as a clear sky (far from the Sun). Or a purchased or home built Flat Field device. Exposures are typically in the 1/2 to 5 second range and should produce images with the peak of the histogram on the camera display near the middle of the graph. It is important that no pixels are pure black or pure white. Flats are used to removed vignetting, dust shadows, etc.

Terminology Continued

Bias Frames or Bias Images (not required and the least important)

These are the images taken with the scope covered as with the Darks. They are taken with shortest exposure time to which you can set the camera (1/2000, 1/4000 sec, etc). You must use the same ISO setting as the images you are going to subtract them from.

Some sources will say when stacking images, to subtract the Bias frames from both the Darks and the Flats. However, since the bias in the Darks is the same as in the Lights and the Darks will be subtracted from the Lights there is no need to subtract it from the Darks.

Due to the nature of the camera sensor, when the data is read from the sensor there is a small offset (bias) included in the signal. It is recommended by some but it is not necessary to remove this bias when processing your astro-images to make pretty pictures as it is a very small part of the image signal.

Basic Steps for Stacking Astro-Images

Your preferred stacking software may not be able to do all of the following. For example. Registax cannot use Bias Frames. Some steps don't have to be done in the order listed. Some software allow you control the order, in others, it's all done "behind the scene".

•Inspect your Light Frames and delete any in which the stars trailed too much or clouds interfered, etc. You may also want to remove images with satellite trails, however, if you have enough images, the stacking process will reduces the visibility of them. Also most software has what's called Sigma Clipping, which, when applied will remove satellite trails.

•Stack your Dark images creating a "Master Dark".

•Stack the Flat field images creating a "Master Flat".

•(Optional) Stack the Bias images creating a "Master Bias".

•(Optional) Create a Bad Pixel Map from the Master Dark.

Basic Steps for Stacking Astro-Images

•Stack (combine) your Light frames applying the Master Dark, Master Flat and optionally the Master Bias.

-If you made a Bad Pixel Map apply it here to each Light Frames, we will call the resulting images Lights minus BPM. T*his removes any the Hot Pixels*. *If you use the Hot Pixel Map you skip the next step of applying the Master Dark to the Light Frames*.

-The apply the Master Dark to each Light Frame. The Master Dark is subtracted from each Light Frame. We'll call these Light minus Dark images.

-If you are using Bias Frames apply them to your Master Flat at this time.

Basic Steps for Stacking Astro-Images

-The apply the Master Flat to each of the Lights minus BPM (or Light minus Dark) images. *The Light minus Dark images are divided by the Master Flat. The brightest pixels in the Master Flat are assigned a value of 1 (typically pixels in the middle of the image). Darker pixels get assigned values less than 1 (typically pixels on the edges and in the corners of the image). Let's say the corners are only 80% as bright as the center. They are given a value of 0.8. If you divide a pixel with a value of 0.8 by 0.8 you get a value of 1.0. This means the corners will now be as bright as the center.*

-The "final" step in combining the images is the actual stacking. *The average value of each pixel in each location is calculated and used to create the final image.*

-If you used the camera's RAW images, depending on the software you use, you will need demosaic the stacked image.
Go back to the slide about how color images are created.

Basic Steps for Stacking Astro-Images

Some software will allow you to simply select the different sets of images, Darks, Flats and Lights, and automatically does the processing. Others are capable of recognizing each type of image so no manual selection of the different types of images is required. Some software requires you to process Darks, Flats and Biases in separate steps before combining them with and stacking the Lights.

Some software allows the creation of what's called a "Hot Pixel Map" which maps out the location of hot pixels in the Master Dark. When the Hot Pixel Map is applied to the Light frames the artifacts caused by hot pixels are removed. Some people only use the Hot Pixel Map and don't apply the Master Dark to the Light frames.

File Formats

This is not an exhaustive discussion of image file formats. Some common formats are **RAW, TIF (or TIFF), FITS (or FIT or FTS), JPG (or JPEG, JPE)** file formats. Most DSLR cameras save images as JPG files and this is the format most people are likely to be familiar with. Though JPG format can be used, and is fine when starting out, it is not generally used for astro-images except for sharing copies via email or posting on the web.

RAW is not actually a format but the general term for any "raw" camera format. Each brand of camera and even different models from the same company can have different "raw" formats. RAW files essentially contain the data as it comes out of the camera's sensor and has had little or no processing by the camera. It is the most pristine data available from the camera. Most DSLR's allow the user to save images as a RAW image. *See the slide about how color images are created.*

File Formats

FITS format is typically the format used with specialized astro-imaging cameras and with many image stacking applications. It is similar to RAW, in that when data from the camera sensor is saved it is unprocessed or minimally processed. Unlike RAW it can also be used for saving processed images. FITS was designed specifically for professional astronomy and is a very versatile format.

FITS and TIF are commonly used when stacking images and during post-processing because they are typically used to save images in an **uncompressed** format (RAW files are also uncompressed can not used for saving processed images). Images can be opened modified and resaved without loosing image information. However, Information can be lost as a result of the processing if some of the pixels become saturated (pure white) or become pure black.

Bits and Color "Depth"

This part is a little more involved, harder to explain and depending on one's exposure to binary numbers (base 2 numbers) harder to follow. I will try to keep it reasonably straight forward.

Spatial resolution has to do with how many pixels makes up an image. **Color resolution or color depth** has to do with how many bits, as in binary number bits, are used to represent the value of each color of each pixel. In astro-imaging you typically need lot of color depth because you subject often very faint and will need to be brightened a lot (stretched).

A binary number with **8 bits can represent 256 levels of brightness (2^8 = 256).** This is the color depth of JPG images, is what a computer monitor displays and matches well with what the human eye can perceive. It is also, conveniently, 1 byte in computer language.

00000000 = 0 = the minimum value or black

01111111 = 127 = halfway between black and white (a medium gray)

11111111 = 255 = the maximum value or white

Bits and Color "Depth" Continued

A binary number with **16 bits (2 bytes) can represent 65,536 levels of brightness (2^16 = 65,536)**. TIF and FITS files typically use 16 bits per color channel, sometimes referred to as 48 bit color (16 bits x 3 color channels).

00000000 00000000 = 0 = the minimum value or black

01111111 11111111 = 32,767 = medium gray

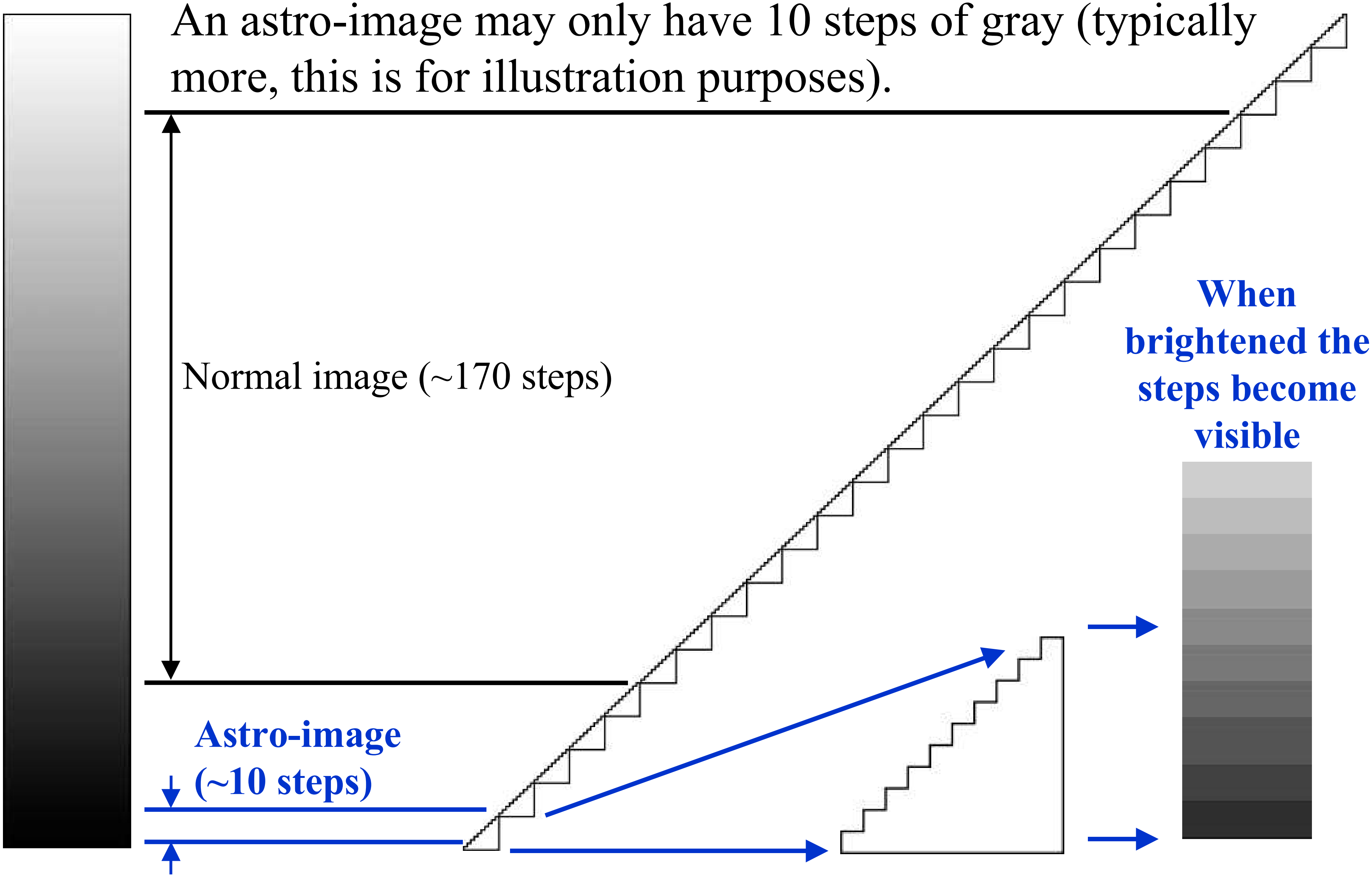
11111111 11111111 = 65,536 = the maximum value or white

RAW files from most DSLR's **have 14 bits per color channel (2^14 = 16,384)**. Image files from specialized astro-cameras will have 12, 14 or 16 bits (up sampled to 16 bits for stacking).

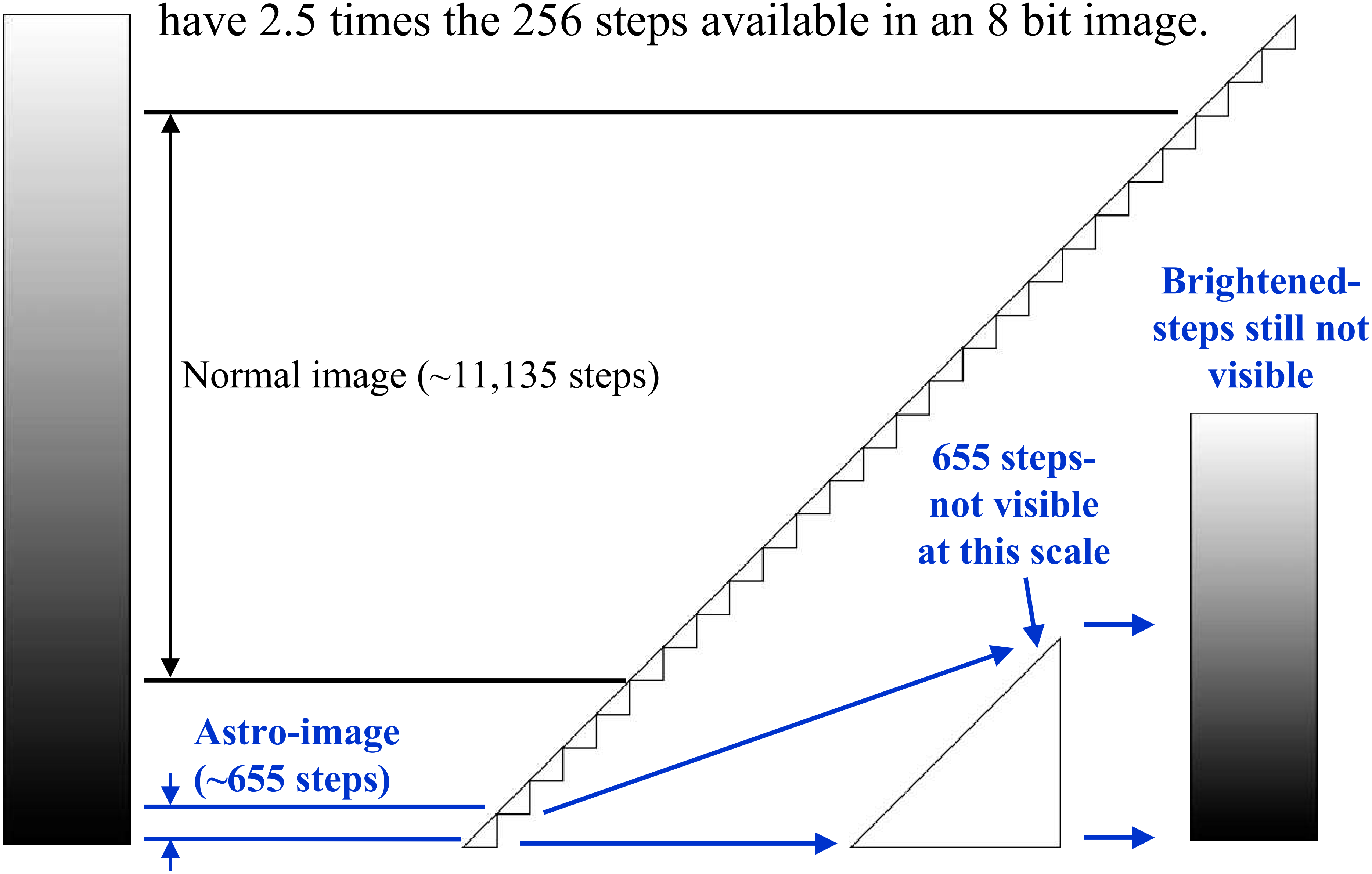
Because 8 bits per color matches well with what the human eye can perceive one may wonder why you would ever want or need 16 bits. The answer goes back to the fact most astro-images are very dark, they are no where near as bright as your typical everyday image.

8 bits - On the left is a grayscale bar showing the brightness range of normal and astro-images. On the right is 250 steps, marked with a triangle every 10 steps, closely representing the 256 steps of 8 bits color.

An astro-image may only have 10 steps of gray (typically more, this is for illustration purposes).



14 bits (typical sensor color depth using RAW format) - On the right is 16,384 steps (2^14) marked every 655 steps. Here the astro-image has 65 times more steps than if saved as an 8 bit image. The astro-image will have 2.5 times the 256 steps available in an 8 bit image.



Bits and Color “Depth”, Additional Notes

The information on the previous 2 pages is not exact but is good for comparisons. The advantages of saving the images in the camera’s RAW format are clear, more color depth. Vaguely similar to a camera with a sensor with more mega pixels can provide more data and therefore a better looking image.

Even though a high ISO setting will make the image brighter it will not provide more color depth as the ISO (gain) is applied after the exposure is completed. Increasing the ISO does not create more steps it only “moves” each step further up the brightness or “staircase”.

Also based on the information on the previous 2 slides, converting from the camera’s RAW files or TIFF files to JPG will obviously reduce the steps per color.

What is signal?

Signal is the light from the object you are imaging.

What is noise?

Noise is anything that shows up in the image that is not produced by light coming directly from the the object. Sometimes referred to as **unwanted signal.**

What is signal to noise ratio (S/N Ratio)?

It is simply the ratio of the Signal to the Noise. The signal and noise can be measured and characterized numerically and one divided by the other, often denoted as **S/N Ratio** or sometimes just S/N. The larger the signal is relative to the noise the higher the ratio and the better the image.

Improving S/N Ratio

Increase the amount of light reaching the sensor.

- By increasing the exposure time and/or total exposure time.

- By using a telescope with a lower the f/ratio. *This applies to extended objects like galaxies, emission nebulae, reflection nebulae and the sky background. Does not apply to stars or star clusters. Using f/6 as a baseline, an f/4 telescope produces an image 2.25 times brighter, an f/2.2 produces an image 7.4 times brighter. 2.25 and 7.4 times more signal per exposure time.*

Decrease the noise.

- By taking lots of images and stacking them. *Much of the noise is random from image to image and pixel to pixel, by stacking many images this random variation is averaged and therefore reduced in the final image.*

- Cool the camera. *Much of the noise is affected by temperature.*

Noise (additional info)

It shows up as graininess in an image. It is also unwanted light and any other "signal" that is not produced by light coming from the subject.

Sources of noise in cameras are:

***"Hot" and "warm" pixels** (show up as brighter pixels on every image) due to minor defects in photosensors on the imaging sensor. This is normal. **Temperature affects the brightness of hot and warm pixels**.*

*The **electronics that "reads" the signal** from the photosensors.*

*The **electronics that amplifies the signal.***

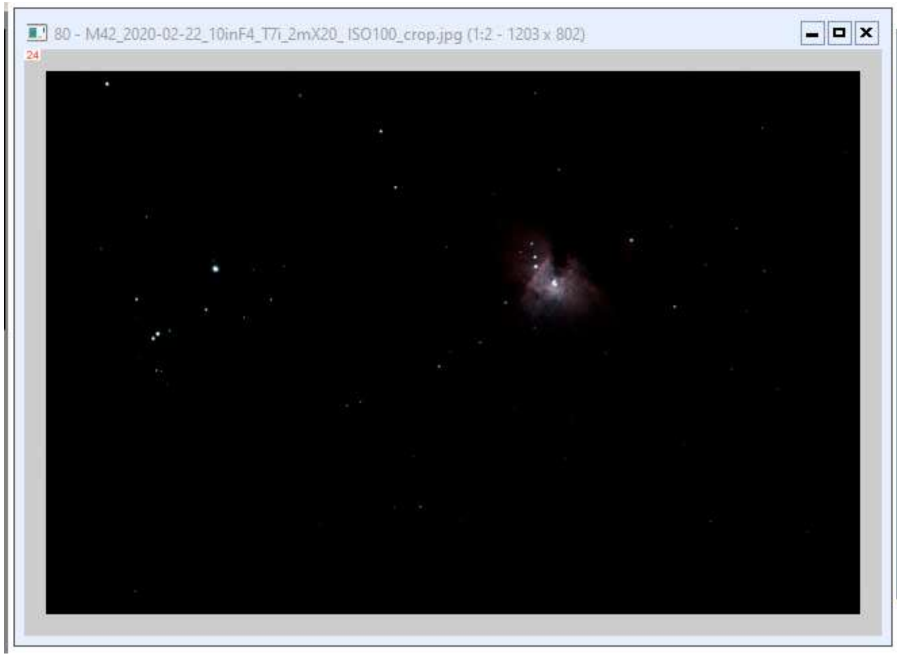
***Conversion of the analog readout to a digital number** (changes the "smooth" analog signal to a stepped signal) which adds noise by rounding up or down to the nearest step.*

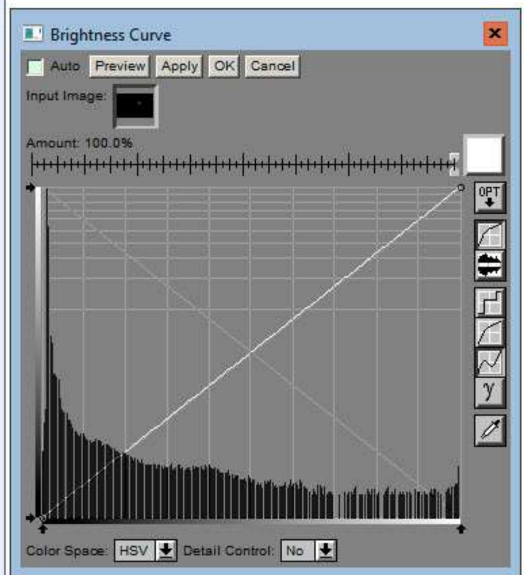
***Cosmic ray strikes** (show up as occasional randomly located "hot" pixels).*

***Vignetting -** light blocked from the corners (or other areas) of the sensor making them darker than the middle of the picture.*

"Stacking" images reduces the noise from most of these sources. It does not reduce vignetting, but that is a topic for another talk.

The Histogram





Relative number of pixels at each value.

More pixels

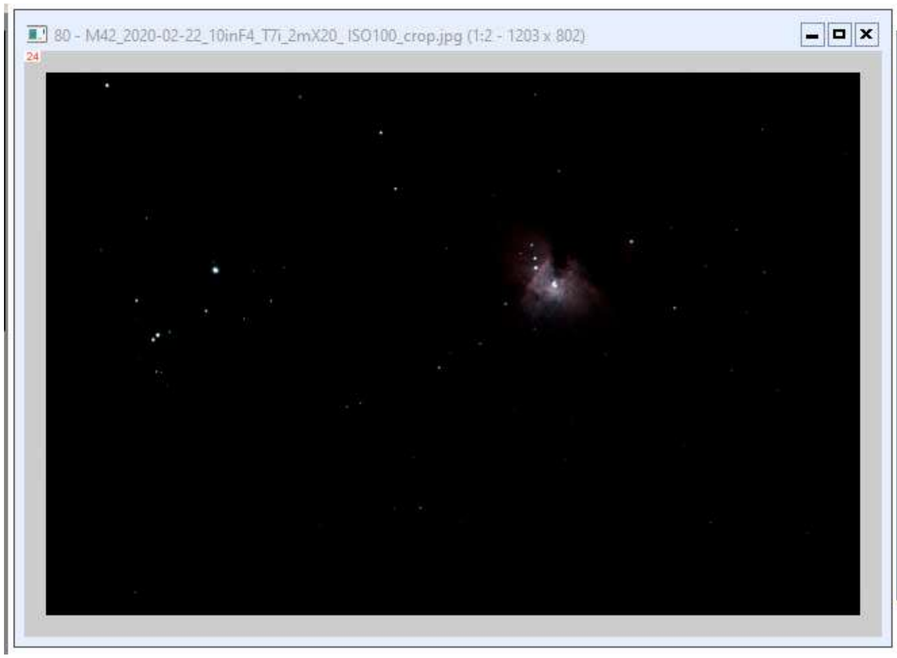
Less pixels

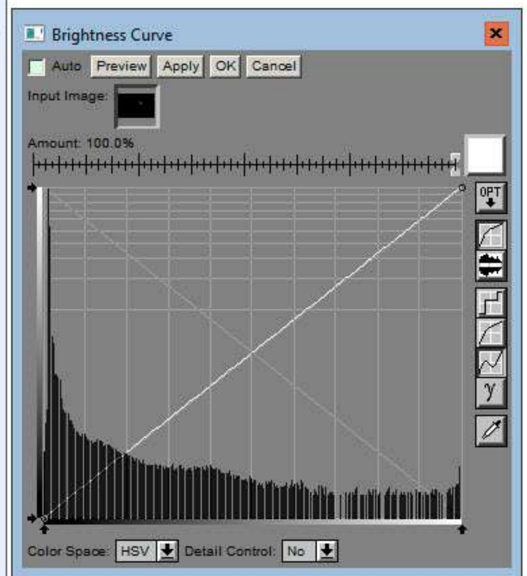
Black White

Value (brightness) of the pixels

The **histogram or brightness curve**, is maybe one of the most useful tools available. It plots the number of pixels (vertical axis) against pixel brightness (horizontal axis). It takes some time to get used to looking at the data this way and using it to make adjustments to the image but is well worth the effort.

The Histogram





Relative number of pixels at each value.

More pixels

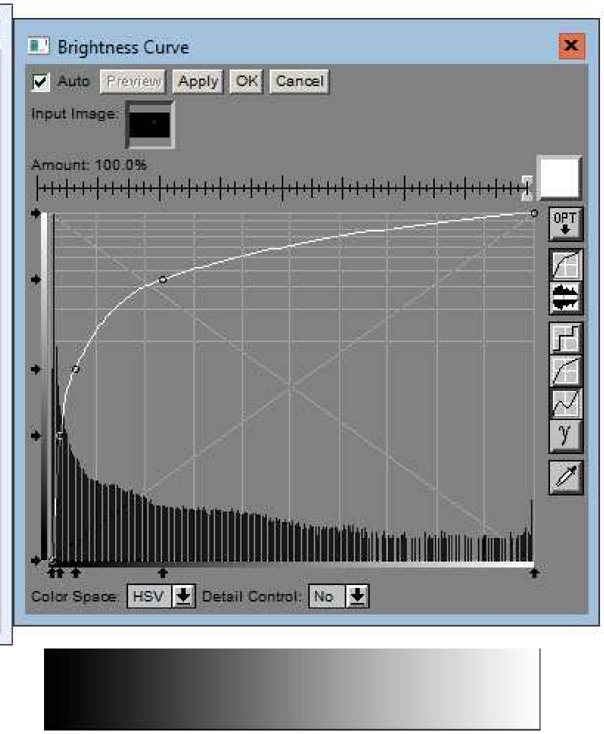
Less pixels

Black White

Value (brightness) of the pixels

The histogram gives you a more accurate "picture" of the picture. Most of the pixels **are** very dark but not actually black. The nebula is represented by the vertical lines somewhere in the middle of the graph. The stars, by the lines on the right. Even an image like this with most of the pixels looking pure black has a lot of data hidden in all that blackness.

The Histogram



Relative number of pixels at each value.

More pixels

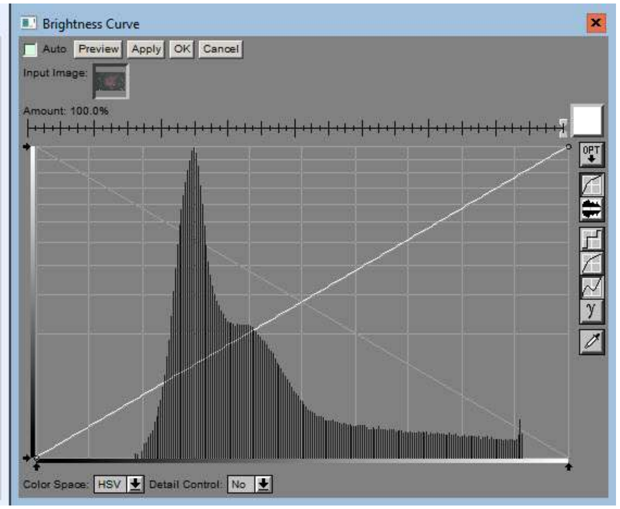
Less pixels

Black ⟷ White

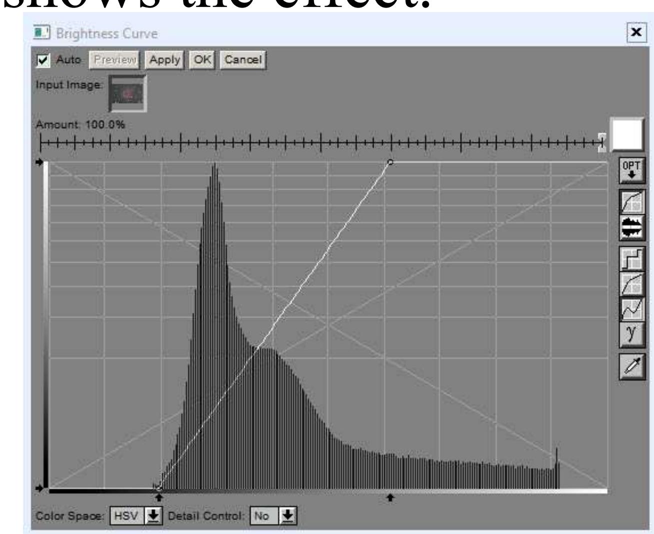
Value (brightness) of the pixels

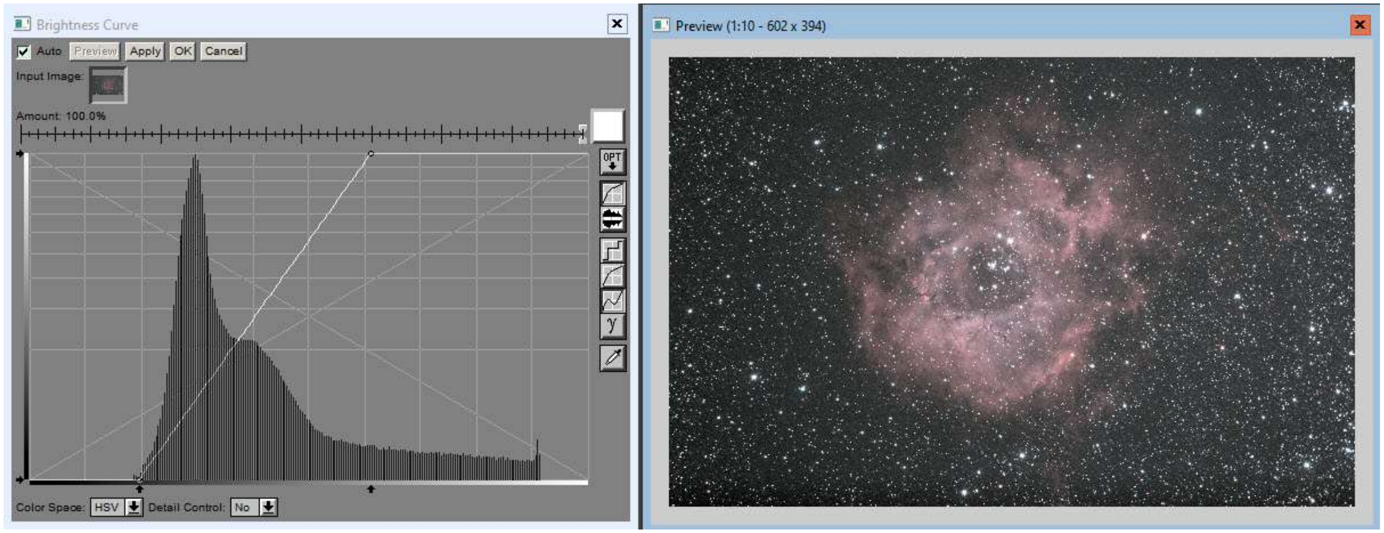
These dark areas can be brightened by applying a **histogram or curve function.** Here you can see some of data in the darker areas.

Making Histogram Adjustments

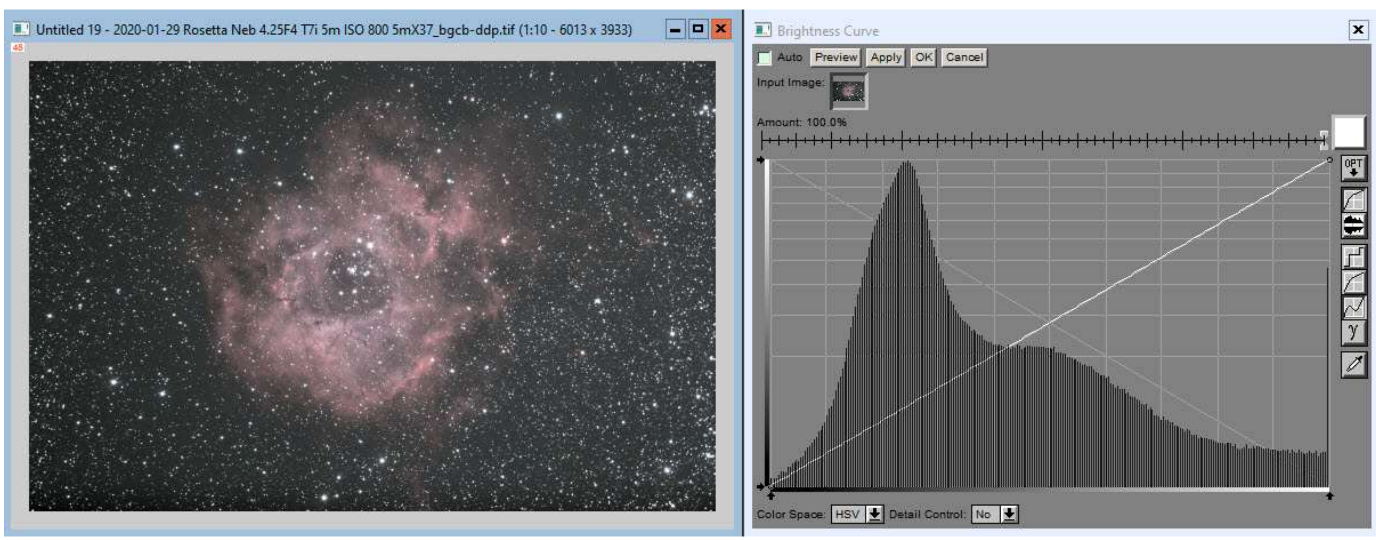


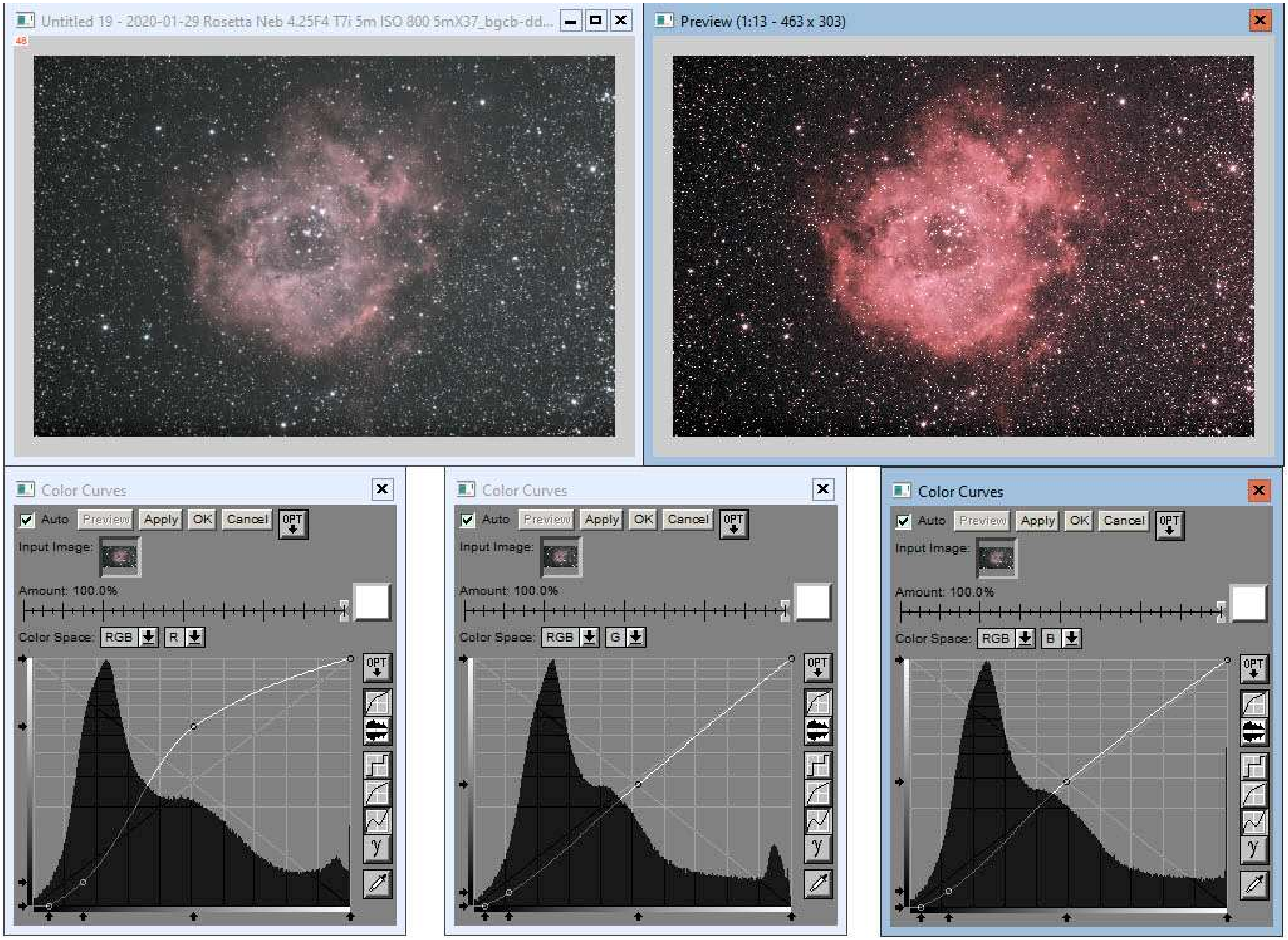
Here the background is too bright and the subject is not bright enough. With this particular software one uses the diagonal white line to make changes. Move the end points as shown below, the preview window on the right shows the effect.



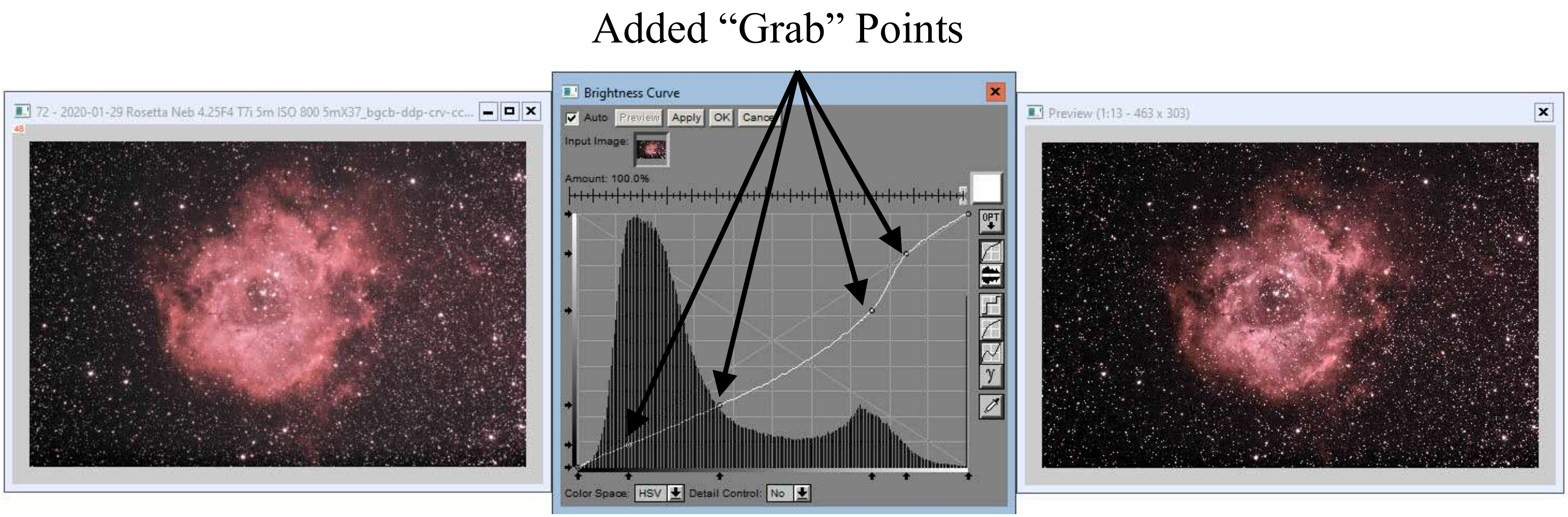


When the adjustment is applied the white diagonal line moves back to it's starting location between the lower left corner and the upper right corner "pulling" the pixel values with it, see below. Notice how the bumps in the graph are wider (stretched out) below compared to the graph above. If more "stretching" is needed, often it is best to apply the curve function a 2nd time.



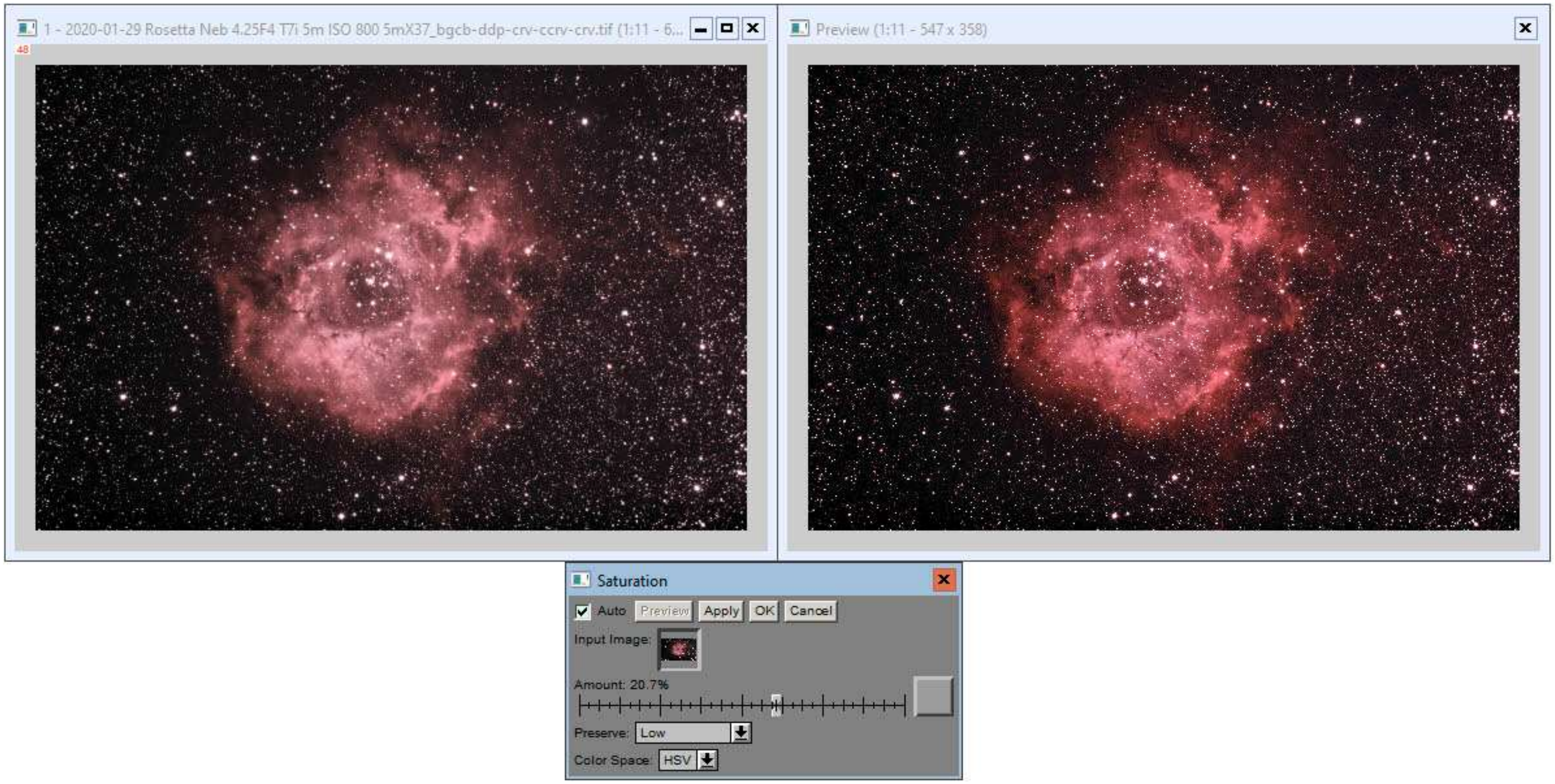


A more powerful tool is a color curve function. Here each color channel (red, green, blue) is adjusted independently. The red (left) brings out the H-alpha emission, here all 3 channels are used to darken the background.



Here’s another example of applying the curve function. This time to highlight details within the nebula. The curve or histogram function in some image processing software allows the user to place “grab points” as done here, giving the ability for complex and nuanced adjustments. Other’s have very limited adjustments. Virtually all “post processing” functions manipulate the histogram of images in one way or another.

Color Saturation



The Color Saturation function makes all the colors more vibrant. The object in this image happens to have a lot of red in it. If you go back two slides you see that this can be done more selectively with the color curve function. With experience you will find that sometimes one function works better than another for a particular image and vice versa for another.

When your are done, hopefully you have turned what was a dark or washed out image into a masterpiece you are proud to show off!

A partial list of resources:

Stacking Software - most stacking software has some "post processing" functions that are useful even if not as powerful as editing software.

(Deep Sky Stacker) http://deepskystacker.free.fr/english/faq.htm

(Nebulosity) http://www.stark-labs.com/

(RegiStax) https://www.astronomie.be/registax/

Editing Software

(PhotoShop) https://www.adobe.com

(Picture Window) https://www.dl-c.com/Downloads.html (This is now free with request of a donation. This is what the author uses for most of his image processing.)

Created for the Vermont Astronomical Society
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