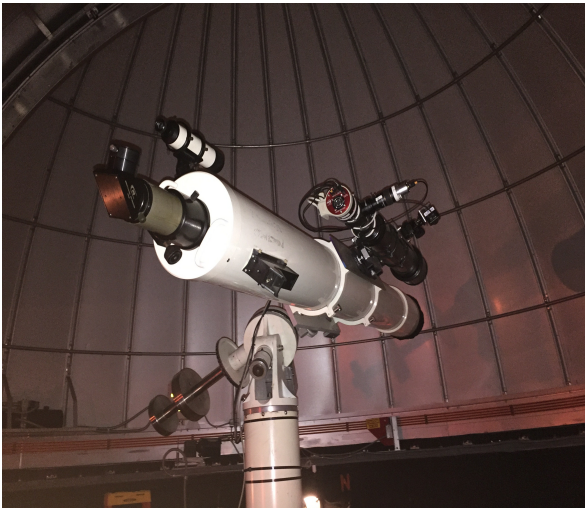


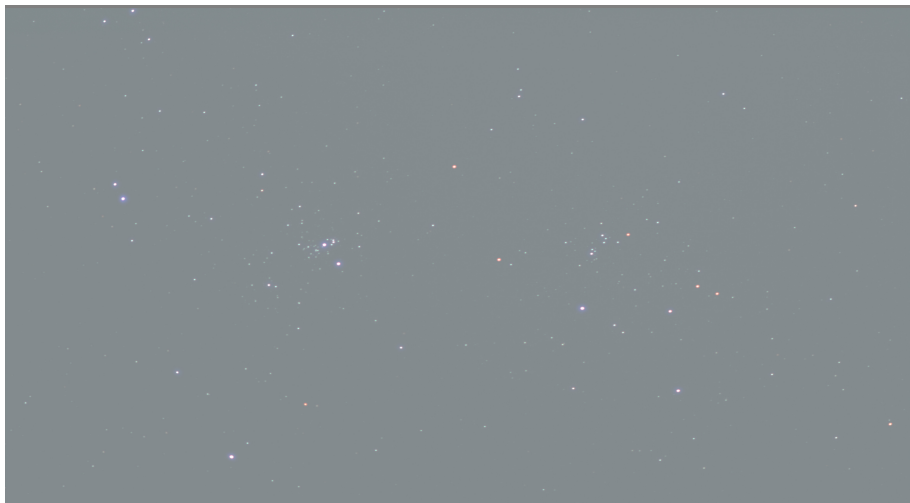
Deep Sky Imaging in Severely Light Polluted Skies - A Technique for Removing the Light Pollution

by Vance Tyree

I have been imaging deep sky objects from the Garvey Observatory in Monterey Park as part of the astronomy public outreach service done by the Los Angeles Astronomical Society (LAAS). This imaging is done using a small telescope piggybacked to the main 8" refractor telescope (white telescope in the image below) in the observatory dome. The imaging telescope (black telescope) is a 120mm aperture (1000mm focal length) telescope with a deep sky camera (Red camera) and a planetary imaging camera (at 90 degrees from the main axis on a flip-mirror device).

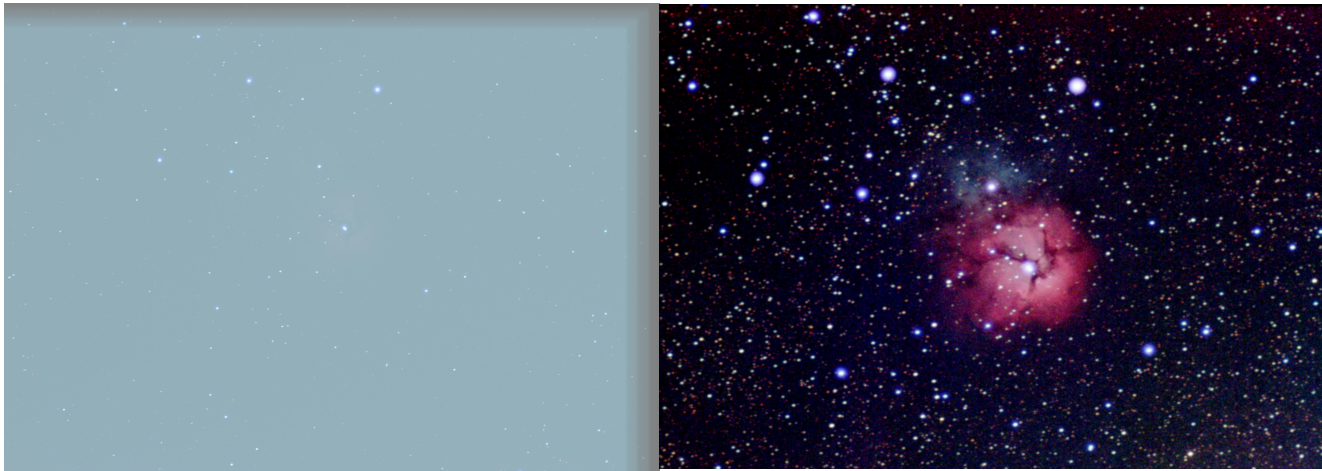


Unfortunately, the Garvey Observatory is located deeply within an urban region with light pollution so severe that only stars the order of second magnitude and brighter can be seen. To make matters worse, the Garvey Ranch Park where the observatory is located, has a brightly lit baseball/football field only about 200 feet from the observatory. This ball-field is fully lit essentially every night, so we have a Bortle 9 sky at best. It is so bright that the first quarter moon has little effect upon our imaging. So, here is a typical deep sky image of the Double Cluster on a night without the moon:



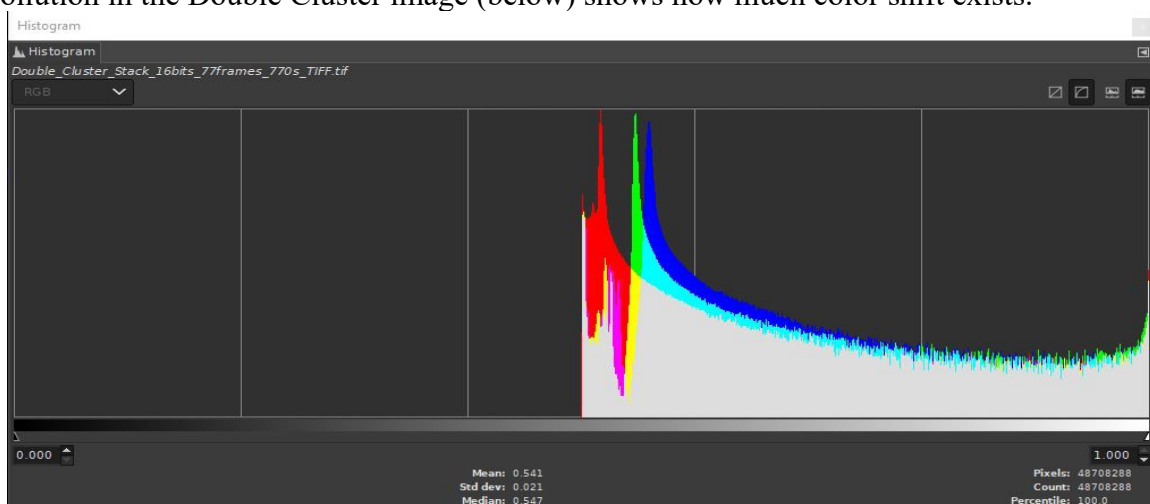
This was a stack of 77 ten-second sub-exposures using Live Stack in SharpCap Pro.

The blue-gray veil of light pollution is so strong that only the brightest stars are evident. Also, the dominant blue-green color of the light pollution shifts the color of the stars to such a degree that the natural star colors are muted. When imaging the more faint deep sky nebulae the object of interest is simply not seen at all. Here is the Trifid Nebula (M20) before and after light pollution removal:



If you look very carefully at the before processing image you may be able to see the slightest trace of red from the Trifid Nebula, but it is essentially a useless image without processing to remove light pollution. The gray strips on top and on the right side of the image are artifacts caused by telescope drive drift because the RA axis (horizontal in the before image) has severe periodic error and the polar axis is not pointing at accurately the celestial pole, so there is both RA and Dec. drift. These artifacts are easily cropped out before image processing.

The most significant characteristics of the light pollution include the presence of a strong color bias which, if not corrected, will imprint the light pollution color on the deep sky image. A histogram of the light pollution in the Double Cluster image (below) shows how much color shift exists.



The very large red, green and blue peaks in the histogram show the color shift problem with the light pollution. Notice that about half of the brightness dynamic range is taken up by the light pollution. Our deep sky object color data is located only a small number of ADU (Analog to Digital converter Unit) values above the light pollution peaks in the above histogram. We need to subtract out the individual light pollution color channels by the amounts shown in the histogram near the peak of each color channel. Simply setting the black point on the total illumination will, in this particular case, remove

almost all of the red and a significant portion of the green from the deep sky image.

The other problem with the light pollution is that there can be brightness gradients. These brightness gradients have two different origins. One is the vignetting in the optical elements in the imaging optics, which can be calibrated out by doing a careful flat-frame master image. The other cause is the presence of non-uniform haze in the sky which reflects or scatters different amounts of light within the camera chip field of view. Fortunately, most deep sky objects can be imaged within a camera field of view of the order of 1.5 degrees by 1.0 degrees, so the non-uniform light pollution scatter is rarely an issue if the telescope is pointed far from a bright object such as the first quarter moon.

So, what can be done to remove the light pollution. Simply setting the black point in the image will result in rather substantial color bias caused by the color of the light pollution. The only sensible solution is to remove the light pollution by accurately measuring the brightness and color of the light pollution and subtract it from the image. This will remove the light pollution without causing a severe color shift in the deep sky object.

The best solution to the light pollution removal is to use PixInsight to process your images. PixInsight is a powerful astronomical image processing software package that is essentially the “Photoshop” of astrophotography. Many of the tools in PixInsight are very difficult or impossible to implement within Photoshop or any other general photography image editor. The tool in PixInsight that can remove the light pollution is the Dynamic Background Extraction (DBE). By setting some parameters in DBE and creating about 50 sample boxes (avoiding star images and nebulosity in the deep sky object) in the light polluted image, it will create an exact copy of the light pollution in the image (with accurate brightness and color). Double Cluster image with the sample boxes for DBE is shown below:



It is then possible to accurately subtract the created light pollution image from the original image to create a deep sky image without the light pollution. The Double Cluster output image from DBE is shown below:



This image can now be brightness stretched using “HistogramTransform” in PixInsight to bring out the very faint portions of the image. The final Double Cluster image is shown below:



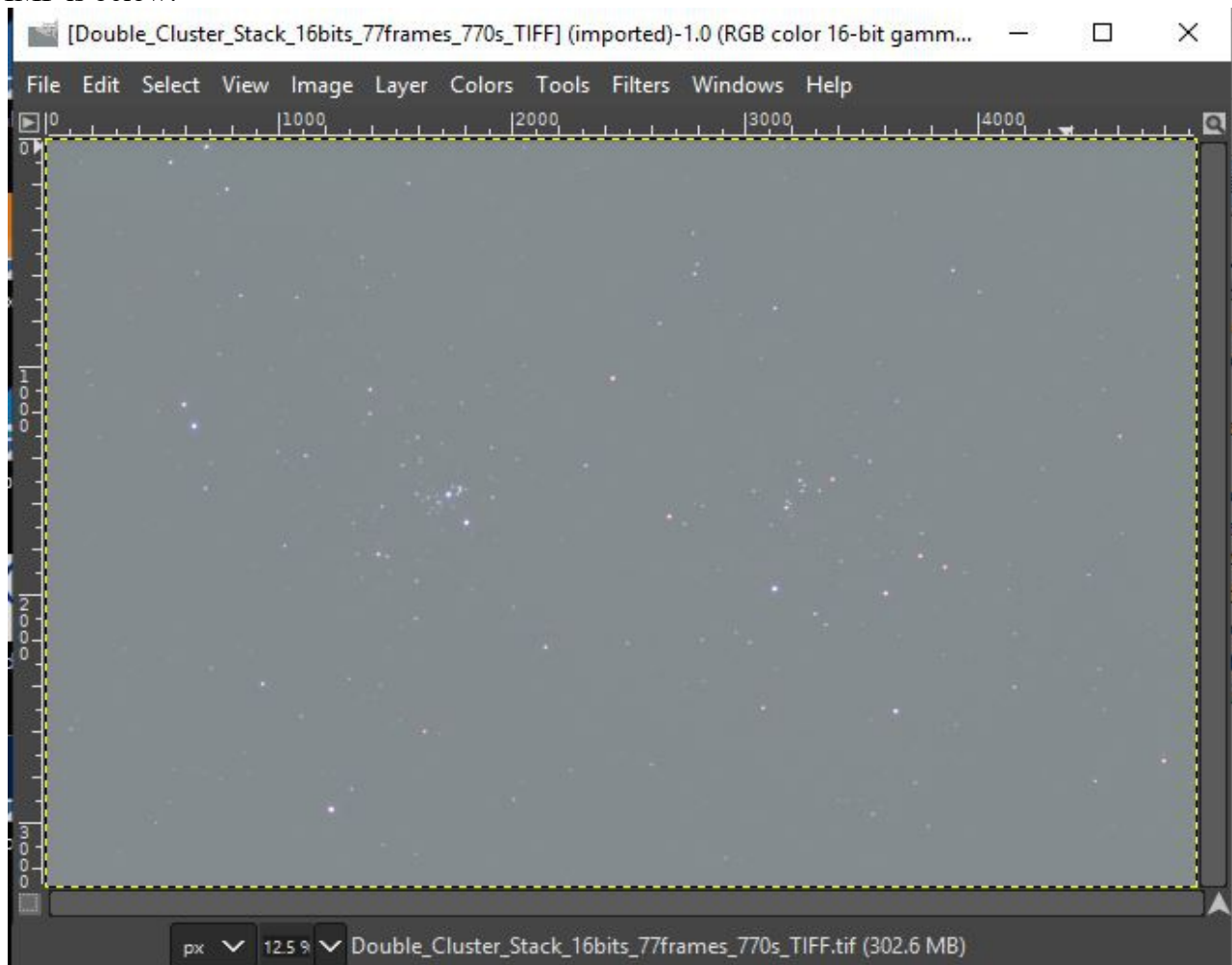
This rather simple process, unfortunately, comes at significant cost. The software license for PixInsight costs 230 Euros (\$250 to \$270, depending upon the exchange rate) which can be a barrier for people who are just starting out in astrophotography, as several people have pointed out to me.

Recently, I have been developing a processing method that can approximate the results that can be obtained with PixInsight using an image processing tool that can be installed at no cost. That tool is called GIMP (<https://www.gimp.org/> - The current version in November 2019 is v2.10.12). It is a fairly close match to Photoshop in its image processing tool sets. The method that I will describe will also work in Photoshop or other general image processing tool with similar capability if you already have it. By the way, the PixInsight license fee is much less than what one would pay for Photoshop.

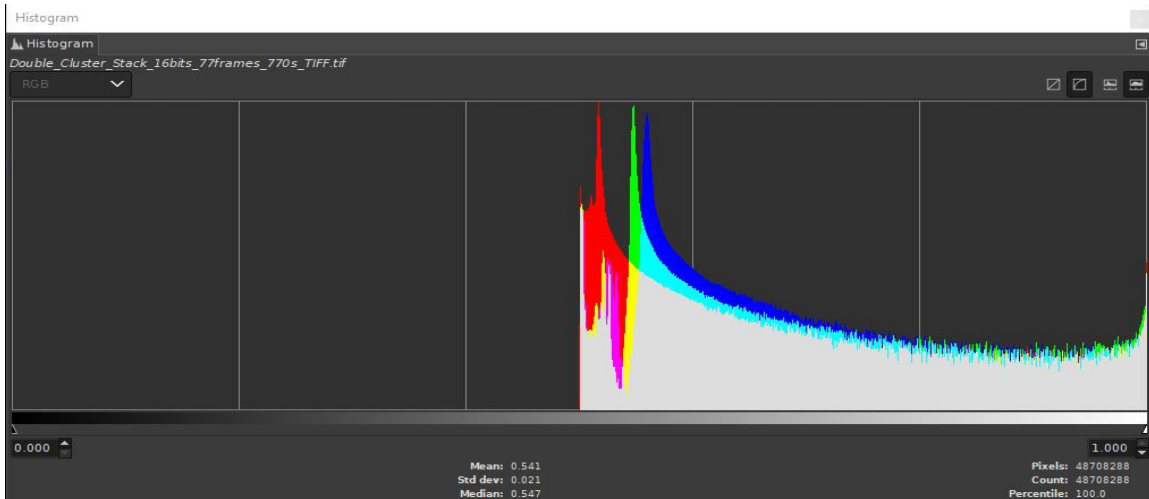
One essential requirement for the the image processing tool to be useful for light pollution removal is that it must be capable of processing images with at least 16-bits per color channel, preferably 32-bits per channel. GIMP can process images with 16-bits per color channel. A very large dynamic range is critical to being able to remove light pollution and leave enough deep sky object dynamic range to stretch the brightness without creating “banding” (gaps in the brightness levels) in the histogram of the processed image. Banding creates some rather unpleasant color and brightness artifacts in the final image.

The first **requirement** for this method to work is to accurately calibrate your deep sky image with dark-frame images and flat-field images. Dark-frames are simply images made by covering the optics to exclude all light using exactly the same exposure time, camera gain and camera chip temperature that you are going to use for deep sky imaging. If you are using a camera that is supported by SharpCap Pro the creation of dark frames can be done using a tool in SharpCap. Also, Sharpcap Pro has a tool for generating flat field calibration images. Prepare the telescope with a light diffusing material over the telescope aperture to produce an absolutely uniform illumination over the telescope aperture. There are several methods for doing this, but I will not discuss these in this article. At this point, your calibrated images will have the light pollution very evenly distributed over the whole image frame (presuming there are no other light gradients as discussed above).

With GIMP lauched, open the stacked and calibrated image. The Double Cluster image opened in GIMP is below:

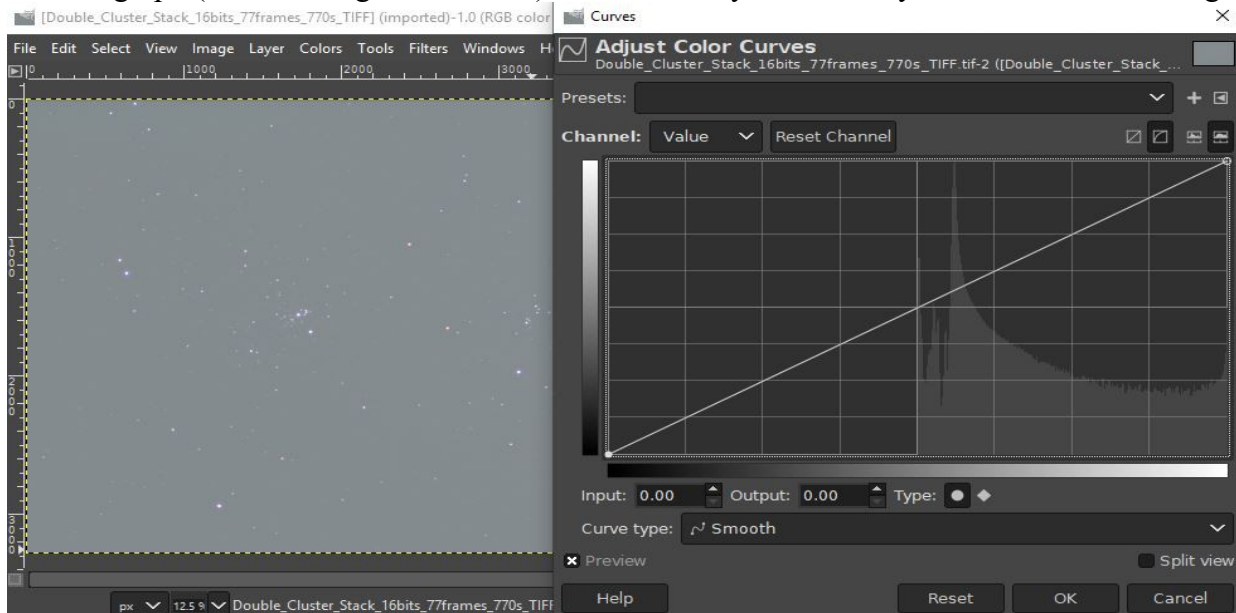


The light pollution removal method is based upon determining the “true zero point” (black point) without the light pollution. This zero point is set to remove the light pollution dark point offset as is indicated by the offset of the entire histogram from the ADU=0 value. In the histogram of the Double Cluster that was previously shown, we need to take a more detailed look at the individual color band histograms. We can see that the entire histogram distribution is shifted to the right (away from ADU=0) by the light pollution. All of the deep sky data is in the remainder of the histogram plot on the right hand side.

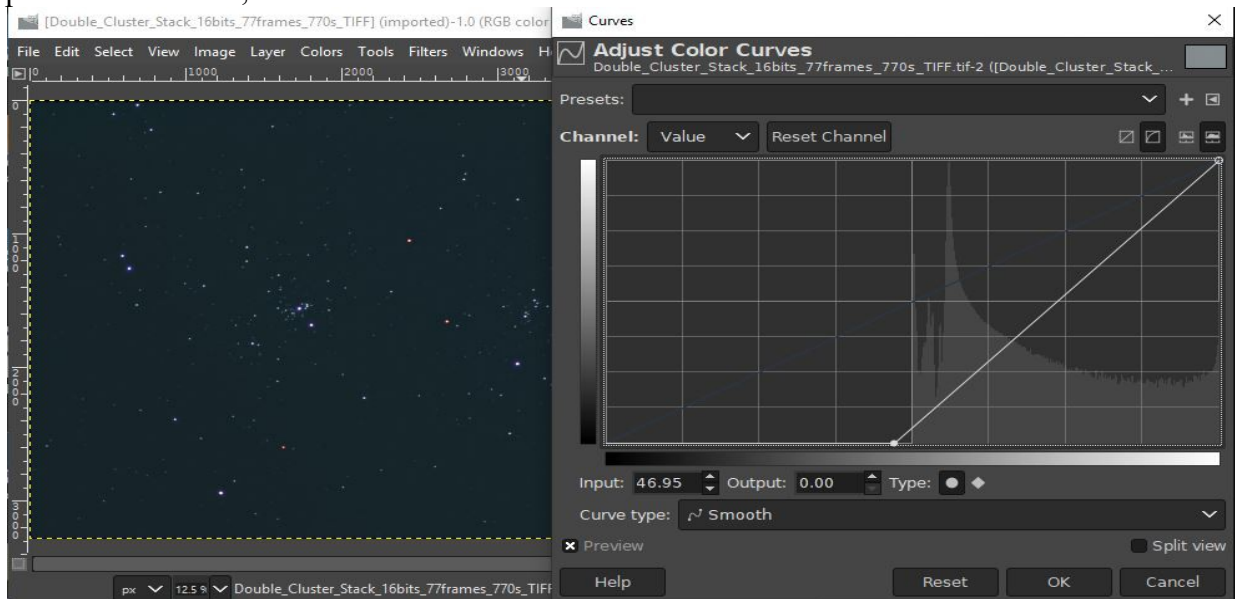


Since the image is calibrated, the light pollution will be the highest peak on the histogram. Also, notice that the three color bands (red, green, blue) have their highest peak at different ADU values. This tells us that the light pollution has a color that will strongly influence the deep sky object color unless the light pollution is subtracted at the three individual color bands. We will be using the Curves tool in GIMP to subtract the individual color band light pollution level.

Let's take a look at the Curves tool. In the screen capture image below, on the left hand side, is our light polluted image. The deep sky image on the left will show the effect that every change in the Curves tool has upon the image if the “Preview” box has a mark in it. On the right hand side of the screen capture is the curves tool that you are using to process the image on the left. Make sure that the logarithmic graph (on the far right of the tool) is selected so you can easily see details in the histogram.

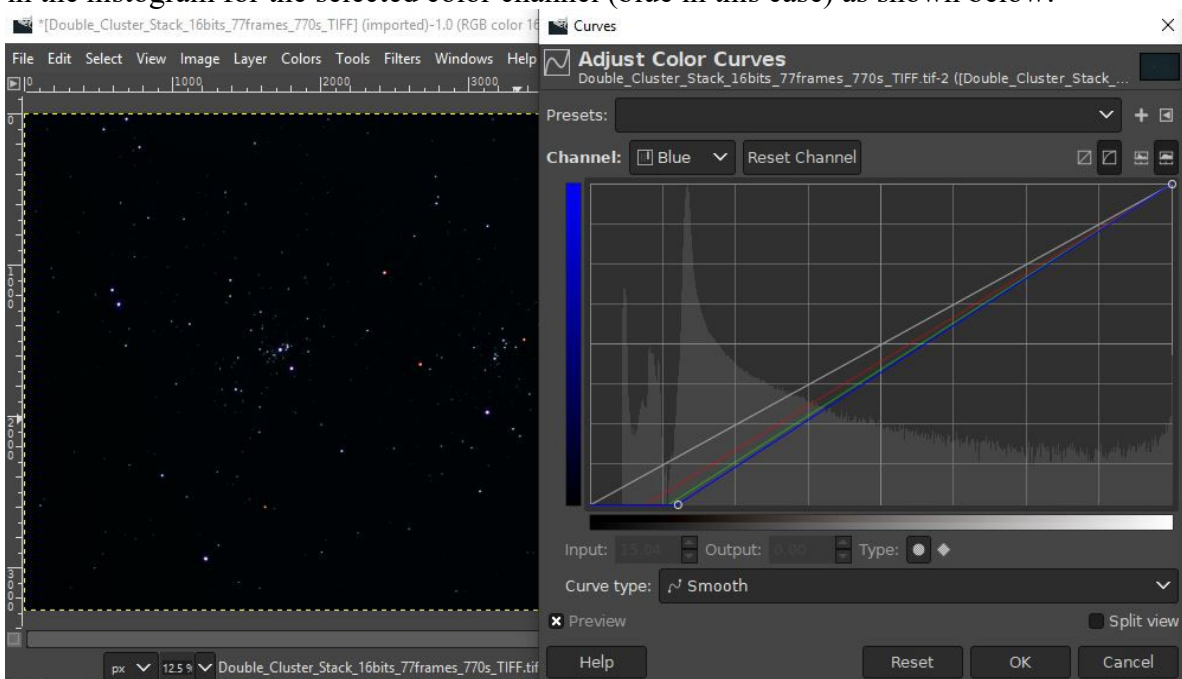


In the above screen capture, I have opened the calibrated Double Cluster image in GIMP and selected the “Curves tool” which shows the histogram of the light polluted Double Cluster image. I can subtract light pollution by sliding the lower left curves black point to the right along the X-axis. You can confirm that you are on the X-axis by looking at the “Output” box beneath the curves graph. The Output should be zero, as shown below:



As you can see from the above image, the background light pollution has been reduced, but the light pollution color remains. Note that the logarithmic scale for the vertical axis is selected as seen in the upper right of the graph. If we take the the black point of the above Curves to just below the sharp rise in the histogram we will remove most of the light pollution and preserve all details in the histogram, while providing more precision in the color selective black point step.

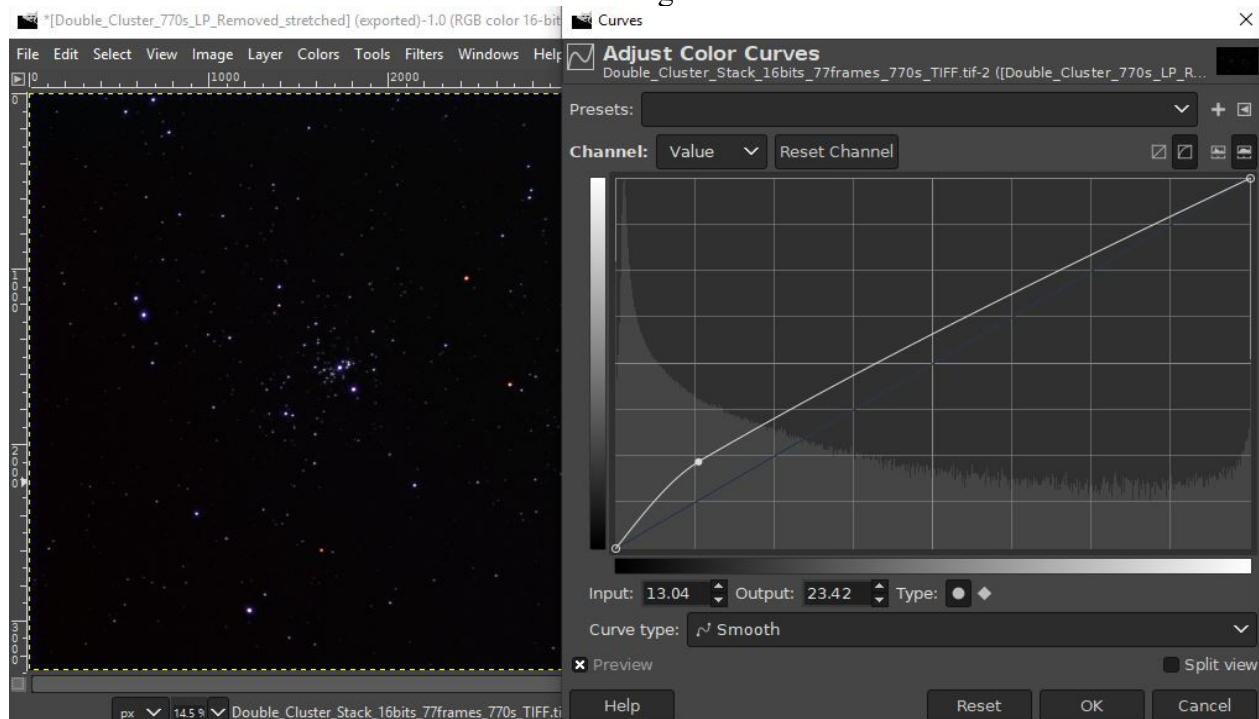
The histogram below has the individual color channel black point adjusted to the left edge of the large spike in the histogram for the selected color channel (blue in this case) as shown below:



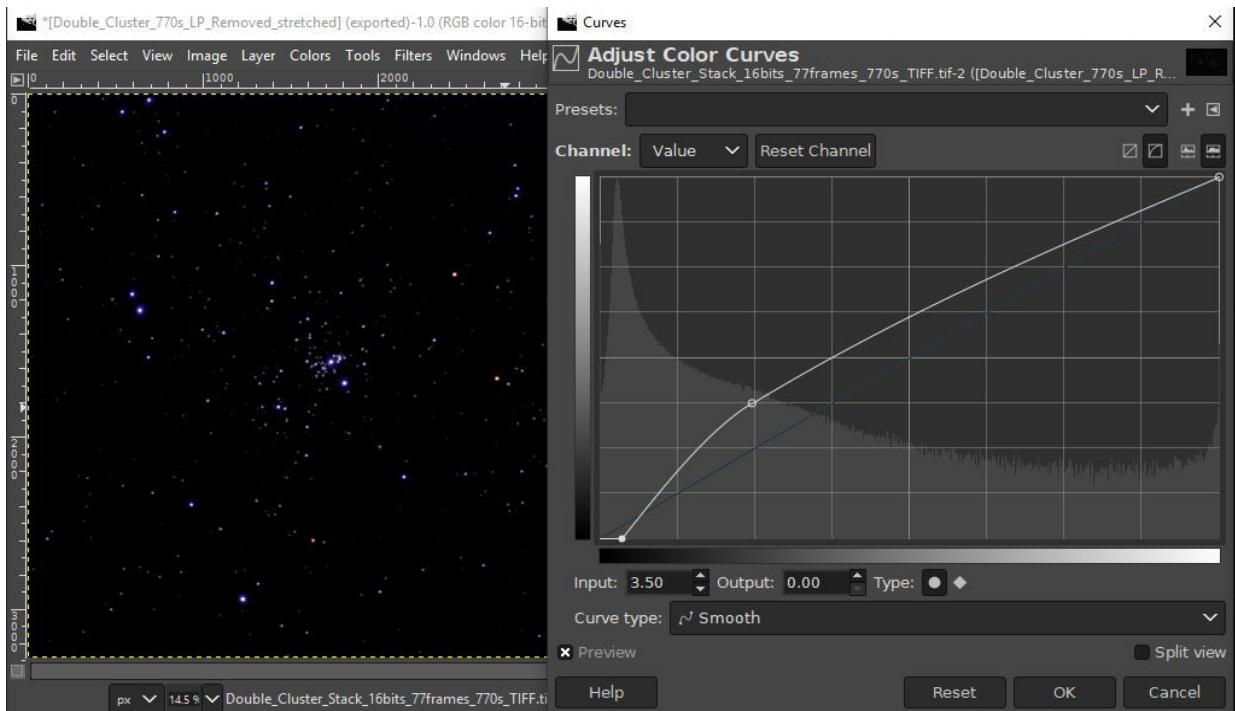
Curves histogram scales the bin count at a particular ADU level into a zero to 100 range and also the ADU range itself (16-bits becomes 0 to 65535) scaled into a zero to 100 range. The key to moving the black point with some degree of repeatability is to find the left edge of the large histogram peak in a particular color channel where it crosses the mid-point in the vertical axis (Y=50). Move the position mark (+) to touch the right-hand edge of the largest histogram peak in a specific color band and read the X-value at that point. Now, move the mouse to the black point marker on the lower left side of the X-axis, select the black point and drag it along the x-axis (holding the left mouse button) until you read X=(value from above) appears in the “Input:” box below the X-axis. If you have trouble getting the exact target value then select the number in the “Input:” box and type in the correct value. Perform this adjustment of black-point in each of the color channels (red, green, blue) selected in the “Channel” drop-down list at the top of the histogram graph. You will see the result of these black-point selections in the image if you put a mark the “Preview” box.

Check to determine if the background is neutral gray-black by viewing the pointer information “Pixel” data over the background (making sure no stars are measured) to see if all three color channels (red, green, blue) are roughly the same ADU level (within about 50 ADU between each channel). If one color channel is too large or too small relative to the other channels then adjust the black point for that channel again until the background is neutral. If you are satisfied with the result, then click OK to perform the adjustment to the image. Your image should have approximately neutral sky background color with the three color channels showing about the same ADU level.

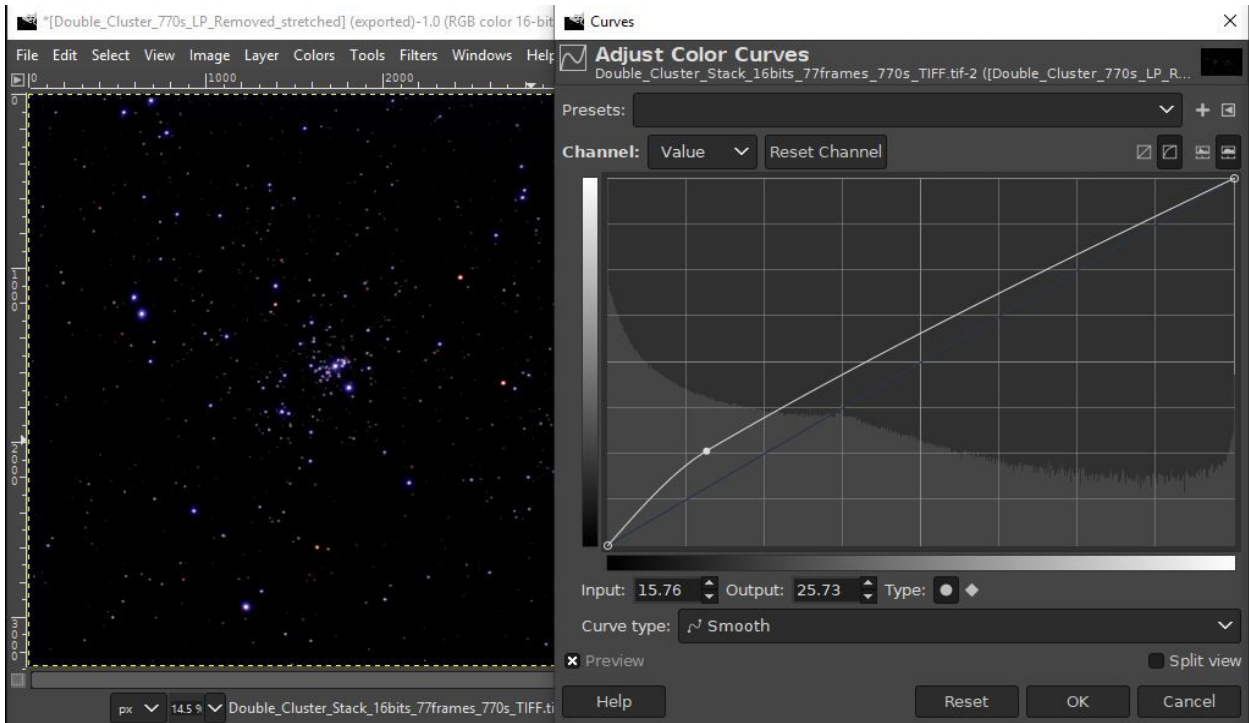
Further applications of Curves can be used to stretch the image dynamic range to show very faint stars or nebulosity. Do not attempt to stretch the image with a single application of Curves. Small incremental stretching with Curves will reduce the amount of bloating in the brighter stars. Use several (2 to 4) modest curves enhancements to achieve the degree of brightening of faint features in the image. The goal is to spread the large histogram peak near the black point out to a higher ADU level, as seen in these three Curves stretches. The three screen captures of 3 applications of Curves to brighten faint stars in the Double Cluster are shown in the three images below:



Curves-1



Curves-2



Curves-3

For this image of the Double Cluster, further stretching with Curves will begin to bloat the brighter stars too much. Considering the amount of light pollution that we have at Garvey Observatory, this final image is rather nice.



I need to emphasize that the flat field calibration of the individual camera images before stacking is the **most important step** in removal of light pollution uniformly over the entire image. If you leave any light pollution gradient in the stacked deep sky images then this method of light pollution removal **does not work** because, even though the light pollution appears to be removed, it will be stretched into visibility when you are stretching the deep sky object into a brighter level. As a result of the importance of flat field calibration in light pollution removal, it is necessary to do the flat field calibration **every time** your imaging telescope and camera are used when you set-up your equipment for imaging.

For the Garvey Observatory, the flat field calibration only has to be done about once every three to six months because the imaging camera and telescope are never separated when the observatory is closed each Wednesday night. In general, if you disturb the camera-telescope interface in any way (remove the camera from the telescope focuser or change the orientation of the camera in the focuser) the master flat field calibration must be done again. Even if the camera-telescope assembly is never changed (as is the case with Garvey Observatory) a new master flat field image must be taken periodically because dust inside the telescope may settle on the camera window producing new “dust doughnuts” that will show up in images calibrated with an old master flat field image.