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Digital Compositing Techniques for Coronal Imaging

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Abstract. The solar corona exhibits a huge range in brightness which cannot be captured in any single photographic exposure. Short exposures show the bright inner corona and prominences, while long exposures reveal faint details in equatorial streamers and polar brushes. For many years, radial gradient filters and other analog techniques have been used to compress the corona's dynamic range in order to study its morphology. Such techniques demand perfect pointing and tracking during the eclipse, and can be difficult to calibrate.

In the past decade, the speed, memory and hard disk capacity of personal computers have rapidly increased as prices continue to drop. It is now possible to perform sophisticated image processing of eclipse photographs on commercially available CPU's. Software programs such as Adobe Photoshop permit combining multiple eclipse photographs into a composite image which compresses the corona's dynamic range and can reveal subtle features and structures.

Algorithms and digital techniques used for processing 1998 eclipse photographs will be discussed which are equally applicable to the recent eclipse of 1999 August 11.

1. Introduction

Total eclipses of the Sun offer a rare chance to observe and photograph the solar corona. Although it is quite easy to record some aspect of the corona on film, it is nearly impossible to produce a photographic image that resembles the corona's appearance as seen by the human eye. The Sun's tenuous atmosphere exhibits a huge range in brightness that cannot be captured in any single exposure because photographic emulsions simply do not have the necessary dynamic range. Short exposures highlight the brightest parts of the inner corona, the ruby red chromosphere and prominences but they fail to record the middle and outer corona. Longer exposures wash out the inner corona and prominences, but reveal faint details far above the limb in equatorial streamers and polar brushes. To render the corona's image more as it appears to the eye, special photographic techniques must be employed.

Gerald Pellett (1998) recently described how he used Adobe Photoshop and a home computer to process and combine a series of eclipse photographs into a single composite image. Using Pellett's method as a starting point, I have spent the past year experimenting with my own eclipse photographs and have produced a more detailed procedure for creating digital image composites

(Espenak 1999). The total solar eclipse of February 1998 provided an excellent opportunity to develop these new techniques. The following descriptions are explicit enough that even novice Photoshop users should be able to create their own digital composites of 1999's total eclipse.

My image processing work has been performed primarily on a Power Macintosh 8500/150 (150 MHz with 138 Mbytes of RAM) using Adobe Photoshop v4.0. Photoshop is a very memory intensive piece of software requiring large amounts of RAM. Although I have run Photoshop on a Macintosh with only 32 Mbytes of RAM, I would consider this a bare minimum and would recommend at least 64 Mbytes of RAM. A Pentium equipped Windows computer will also work well provided it has a comparable amount of RAM. The more RAM and the faster the CPU, the easier it is to perform image processing on eclipse photographs. I have used Photoshop v4.0 on both Macintosh and Windows95 computers, and the software operation is quite uniform on both platforms. The procedures I will describe should work similarly on either type of computer. Since the technique involves large digital image files, plenty of disk space is needed. Photoshop also requires a considerable amount of hard disk space which it uses as a temporary scratch area. I recommend a minimum of 100 Mbytes of free hard disk space, but 200 Mbytes is better. I store my edited image files on Iomega Zip cartridges, which hold about 94 Mbytes of images each.

2. Digital Images

The first step is to convert the 35-mm eclipse images to digital files. A film scanner with a resolution of 2000 dpi (dots per inch) or more is required. If a film scanner is not available, Kodak can transfer images to a Photo CD. Kodak's Photo CD stores each image in five separate resolutions: very low, low, medium, high, and very high. I use the highest resolution (18 Mbytes) for my final work, but I often use the lower resolutions for planning, testing and experimenting. This is important since some Photoshop filters are computationally intensive. It is not uncommon to wait half an hour or more for Photoshop to perform certain operations on large files. It is best to work with small files first until the optimum strategy for processing the images has been determined.

The digital files containing color images used by Photoshop are actually composed of three separate channels or colors: red, green and blue. The individual pixels in each channel have brightness values ranging from 0 (black) to 255 (saturation). All other colors of are produced by mixing the three channels together and by independently varying the brightness value in each pixel.

A good eclipse composite is composed of a number of separate photographs each having a proper exposure for the prominences, inner, middle and outer corona, respectively. I find this requires a minimum of four to five images, but I often use many more to help minimize photographic grain and to increase dynamic range and resolution. Eclipse images can be shot on either transparency film or color negative film. However, negative film is preferred since it has a greater dynamic range and lower contrast than transparency film. Since one of the goals of eclipse composite photography is to lower the overall contrast of the corona, it helps to use a film which is not high in contrast to begin with.

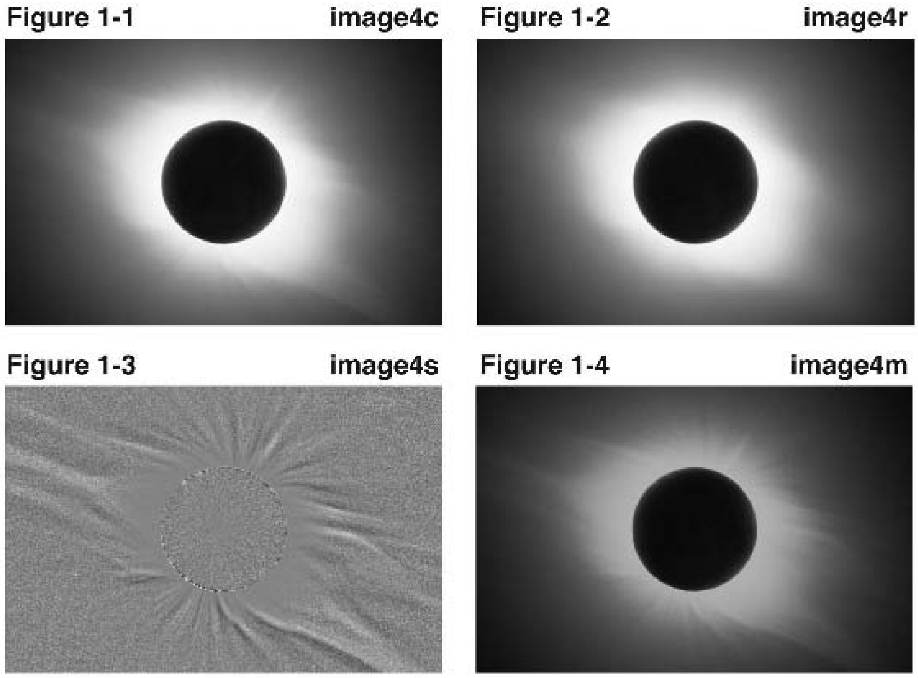

Figure 1. Figure 1-1: Photograph of the total solar eclipse of 1998 Feb 26 (fl=640mm, f/8, 1/2 sec, ISO 100). The first step of the digital compositing process is to crop the image so that the Moon's disk lies at the center of the frame. Figure 1-2: Using the radial blur filter in Adobe Photoshop, an unsharp mask is produce of the original photograph (Figure 1-1). Figure 1-3: The subtraction image isolates fine details and structure in the corona. It is formed by subtracting the radial blur image (Figure 1-2) from the original image (Figure 1-1). Figure 1-4: The multiplication image enhances fine details and structure in the corona. It is formed by multiplying the subtraction image (Figure 1-3) with the original image (Figure 1-1).

3. Cleaning, Centering and Cropping the Digital Image 'c'

After selecting a set of digital images covering a broad exposure range, the next step is to remove all dust specks and scratches from each image. One way to accomplish this is to use Photoshop's *Dust _ & _ Scratches* filter via *Filter/Noise/Dust _ & _ Scratches* menu (select *Filter* menu, then select *Noise* sub-menu, then select *Dust _ & _ Scratches* sub-menu). The *Dust _ & _ Scratches* dialog box allows for the selection of the pixel radius and threshold level (Figure 2). Try values of radius 2 and threshold 15 as starting points. Turn the preview box on and off to see the effect as you modify the filter values. Great care should be taken not filter out real details from the image. A safer though more time consuming method for removing dust and scratches is to use the Rubber Stamp or Clone tool from Photoshop's toolbar. This allows you to replace each dust

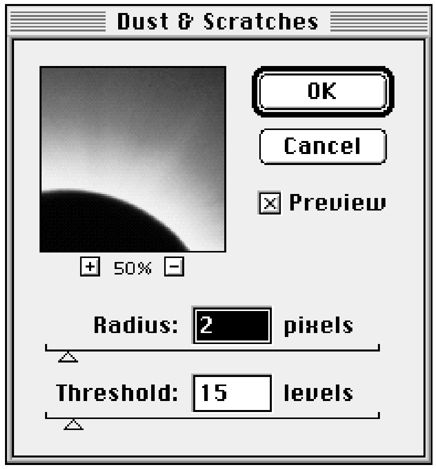

Figure 2. The Adobe Photoshop 'Dust & Scratches' filter is used to remove defects in the original scanned eclipse image (Figure 1-1).

speck or blemish with a small piece of the image immediately adjacent to the dust speck. The Clone tool requires skill, coordination and patience but offers more control than the *Dust _ & _ Scratches* filter. I usually use both tools to clean up an image.

The heart of the corona compositing technique is the use of an unsharp mask created by using the spin mode of Photoshop's *Radial Blur* filter. This powerful filter relies on the fact that the corona's brightness is radially symmetric, at least to first order. The filter will only work correctly if the Sun's (or Moon's) disk is perfectly centered in the digital image. This can be accomplished by trimming the edges off two or more sides of the digital file in such a way that the Moon's disk is then located in the center of the frame.

The first step is to determine the current pixel coordinates of the center of the Moon. The easiest way of doing this is to measure the left, right, top and bottom edges of the Moon's image. Enlarge the image to 200% and open the *Information Window* via the *Window/Show _ Info* menus. Next, use the rectangular *Marquee* selection tool from the toolbar to draw a box with one edge tangent to one side of the Moon (either left, right, top or bottom). The pixel coordinates of the selection box are displayed in the Information Window. Write down the coordinate corresponding to edge of the Moon's limb on a piece of paper. Repeat the process until the pixel coordinates of all four sides of the Moon have been measured. The x coordinate for the center of the Moon's image is simply the average of the left and right positions. Similarly, the y coordinate is the average of the top and bottom positions.

Now it is time to crop off the edges of the image so that the Moon's disk will be perfectly centered. Change the *Marquee* tool to the *Cropping* tool. Next, position the cursor in the image at the x and y coordinates of the Moon's center as displayed in the *Information Window*. It is best to use a magnification of 100% for accurate cursor placement. Now hold down the *Option* key (*Alt* key for Windows users) and drag the mouse diagonally in any one direction while holding

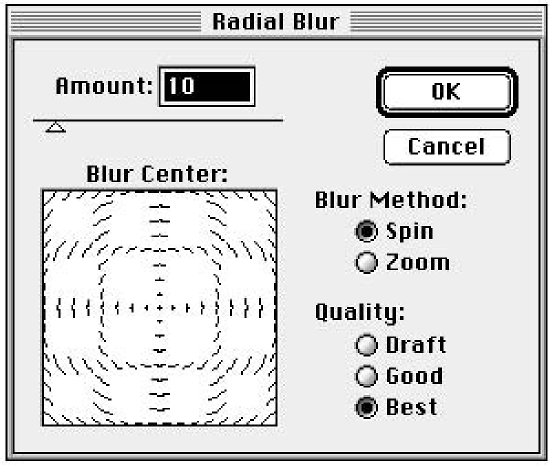

Figure 3. The Adobe Photoshop 'Radial Blur' filter is used to create an unsharp mask of the original eclipse image (Figure 1-1).

down the mouse button. Continue dragging diagonally until the maximum limit is reached (i.e. - when numbers in the *Information Window* stop changing). Release the mouse and keyboard buttons. Hit the *Return* key (*Enter* for PC's) to crop the selection. The Moon's disk is now perfectly centered in the cropped digital image. This should be verified using the steps in the previous paragraph before the cropped image is saved. I usually identify this file (cropped with dust and scratches removed) by appending a 'c' to its name to distinguish it from the original digital file. For example, if the original image is called *image4*, then the cropped image is *image4c* (Figure 1-1).

This process is now repeated on all the other digital files to be used in the final composite. While performing these actions, use the *Information Window* to note the final dimensions (pixels) of each 'c' image file. Besides centering the Moon in each frame, another compositing prerequisite is that each digital image must have the same physical dimensions (in pixels). After centering the Moon in all files, make note of the physical dimensions of the smallest file. These will be used as the common or standard dimensions of all the image files. Open each file and crop it to the standard size using the *Canvas _ Size* dialog box (via *Image/Canvas _ Size*). Use the pop-up menus in the dialog box to change the *New Size* units to pixels, if necessary. Enter the common or standard width and height (in pixels) and hit the *OK* button. Save the file and repeat until all the files have the same physical dimensions.

4. Radial Blur Image 'r'

All files are now the same size and the Moon is centered in each. They are ready to be processed with the *Radial Blur* filter in spin mode. This tool blurs an image by rotating it about its central axis through a user-selected angle. In the process, the brightness values of every pixel at a given radial distance from the

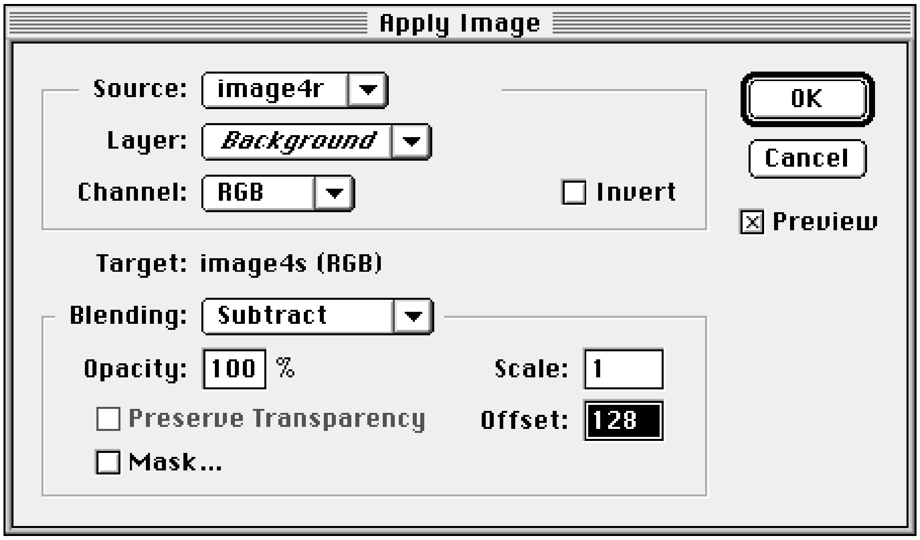

Figure 4. The Adobe Photoshop 'Apply Image' dialog box is used to subtract the radial blur image (Figure 1-2) from the original image (Figure 1-1).

central axis is averaged with all other pixels at the same radius and over the user selected angle of rotation. This arc can have any integer value from 1 to 100 degrees. Experimenting has shown that an angle of 10 to 20 degrees works well. Larger angles result in the loss of small details in the corona.

The *Radial Blur* filter should be performed on a copy of the 'c' image so as not to destroy the original, especially since it will be needed again later. To make a copy of an image, click on the image to select it and then pull down the *Image/Duplicate* menu. When the dialog box appears, modify the copy file's name by appending an 'r' to it (e.g. - *image4r* where 'r' is for *Radial Blur*). Click the *OK* button.

From the menu bar, choose *Filter/Blur/Radial _ Blur*. In the *Radial Blur* dialog box, set the amount to 10 degrees (Figure 3). Choose the *Spin* and *Best* buttons and then click the *OK* button. Now it is time to get a cup of coffee and relax. With a 17 Mbyte file, this filter takes about 30 minutes to run on my 150 MHz Power Macintosh. The time varies with the size of the files and the speed of the CPU. A dialog box displays the relative progress of the filter. Save this image immediately.

It is quite interesting to compare the new 'r' image with the original 'c' image (Figures 1-1 and 1-2). Although the 'r' image preserves the brightness distribution and shape of the corona, it is completely devoid of fine details.

5. Subtraction Image 's'

If God's work is in the details, then the next step is an excellent example. By subtracting the 'r' image from the 'c' image, the resulting 's' image contains all

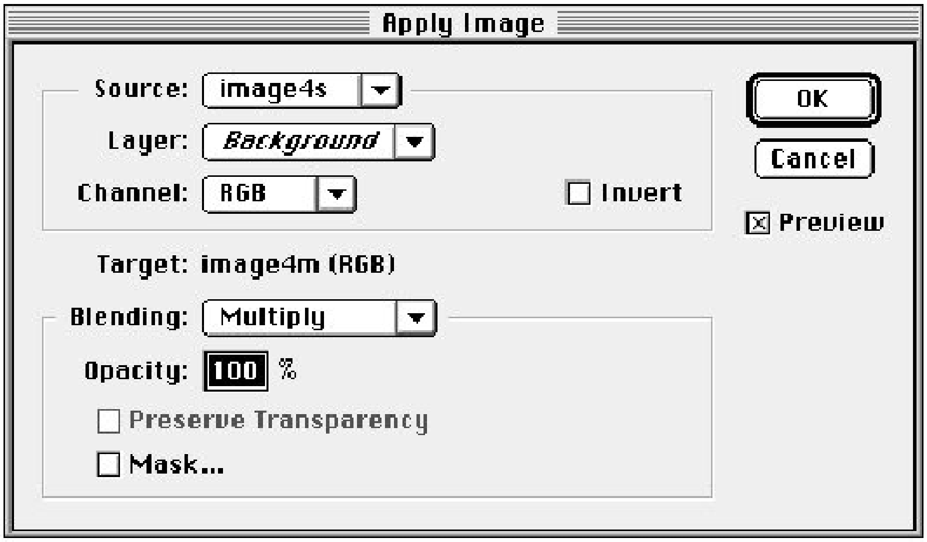

Figure 5. The Adobe Photoshop 'Apply Image' dialog box is used to multiply the subtraction image (Figure 1-3) with the original image (Figure 1-1).

the fine details in the corona without the underlying brightness distribution. In a sense, it is the complement of the 'r' image. In fact, if 'r' and 's' are added together, the result looks almost identical to the original 'c' image.

Photoshop makes it easy to add images together, provided that they have exactly the same physical dimensions. This is why all the images were cropped earlier. To preserve the original 'c' image, click on it and make a copy by selecting the *Image/Duplicate* menu. Append an 's' (for subtract) to the name of the new copy. Next, choose the *Image/Apply ␣ Image* menu. When the *Apply ␣ Image* dialog box appears (Figure 4), use the *Source* pop-up menu to select the 'r' image (e.g. - *image4r*). The target image is the 's' image because it was the last image clicked on. Next, use the Blending pop-up menu to select the *Subtract* mode. When this is done, two new input fields appear: *Scale* and *Offset*. These are used to determine how the two images will be blended together. In this case, *Scale* should be set to 1 and *Offset* to 128. All other controls should be set as shown in Figure 4.

The *Offset* value deserves a short explanation. As discussed earlier, each image is composed of red, green and blue channels containing pixels with values from 0 to 255. The subtle structure in the corona is typically just a couple brightness values higher or lower than the underlying background. For example, imagine a pixel in some fine detail in 'c' which has a value of 100, and an underlying corona in 'r' with a value of 97. When image 'r' is subtracted from 's' ('s' is actually a copy of 'c'), the resulting pixel will have a value of 3 (=100-97). Now consider the opposite case where the pixel in 'c' is 97 and the background pixel in 'r' is 100. The new value after subtraction will be -3 (=97-100). Since Photoshop cannot display negative brightness values, the new pixel brightness will default to 0. The net result of this thought experiment is that information will be lost whenever a pixel in 'c' is darker than the corresponding pixel in 'r'. The solution is to add a scalar to all pixels when the subtraction is performed. The scalar value 128 is chosen as this offset because it is midway between 0 and 255. A value of 128 appears as a medium gray shade when displayed in black and white.

The *Apply _ Image* dialog box also has a *Preview* check box. Selecting it shows what the blended image will look like before the operation is performed. Once all parameters have been set correctly, click on *OK*. Save this image immediately. The new 's' image will appear gray and nearly featureless, but closer inspection will reveal subtle coronal details. The contrast in Figure 1-3 (*image4s*) has been exaggerated to show this detail more easily.

6. Multiplication Image 'm'

Now that an image has been produced containing the corona's fine detail (*images4s*), it can be used to enhance the original image (image4c) by multiplying the images together. Once again the 'c' image must first be selected and duplicated via the *Image/Duplicate* menu. Append an 'm' (for multiply) to the name of the new image. Choose the *Image/Apply _ Image* menu to activate the *Apply _ Image* dialog box (Figure 5). Use the Source pop-up menu to select the 's' image (e.g. - '*images4s*'). The target image is the 'm' image which is currently a copy of 'c'. This time the *Blending* pop-up menu must be set to *Multiply* mode. All other controls should be set as shown in Figure 5.

Click *OK* and save the result. The 'm' image will appear like a darker version of 'c', but with enhanced coronal detail (Figure 1-4).

Of course, fine structure in the corona has been revealed only in those portions of the 'c' image which were properly exposed to begin with. Using a series of images shot at different exposures, a detailed image of the corona can be constructed over a much broader dynamic range than is possible with more conventional photographic techniques. The radial blur, subtraction and multiplication operations must now be performed on each of the 'c' images.

7. Assembling the Composite

Figure 6 illustrates the complete process for a set of four eclipse images. The author took them on 26 February 1998 from Aruba. An 8-cm f/8 refractor telescope was used to make exposures at shutter speeds of 1/125, 1/30, 1/8 and 1/2 second on Kodak Royal Gold 100 color negative film. After processing, the images were transferred to a Kodak Photo-CD. The top row shows the cleaned, centered and cropped 'c' images. The second row contains the radial blur 'r' images. The third row shows each of the subtracted 's' images, but with the contrast exaggerated for clarity. Finally, the bottom row has the final multiplied 'm' images.

At this point, a composite image can be assembled by adding all four 'm' images together. First make a copy of the 'm' image with the shortest exposure (i.e. - *image1m*) via *Image/Duplicate* and call it *comp1*.

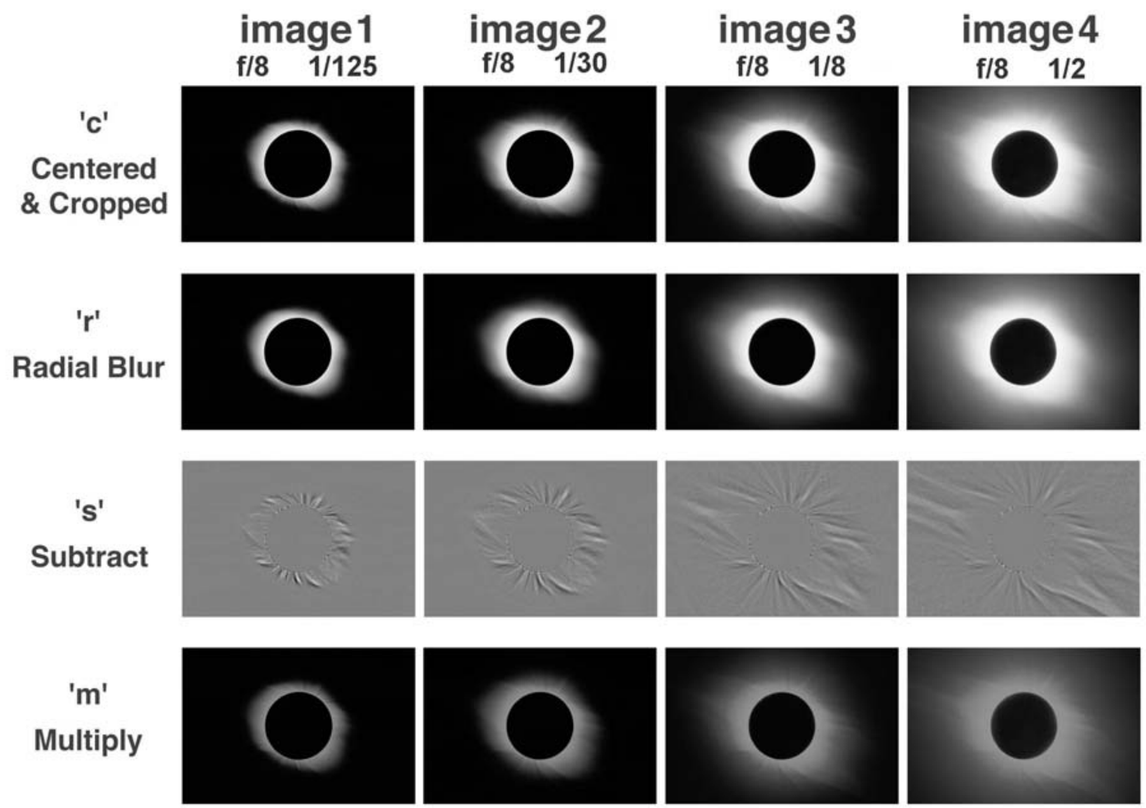

Figure 6. The steps described in Figure 1 must be repeated for each exposure in a sequence of eclipse photographs. This figure illustrates all intermediate steps for a set of four eclipse photographs taken as shutter speeds of 1/125, 1/30, 1/8 and 1/2 (F/8, ISO 100).

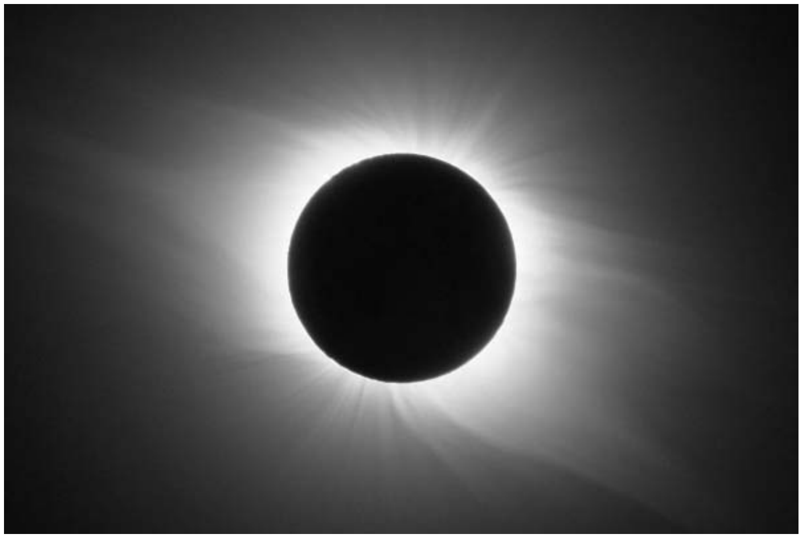

Figure 7. A composite image is assembled by adding all four 'm' (multiply) images together from Figure 6. The Adobe Photoshop 'Apply Image' dialog box was used to add each image using settings of Scale=1.4 and Offset=0.

This will form the foundation of the composite. Now select *Image/Apply _ Image* to bring up the *Apply _ Image* dialog box. Change the *Source* pop-up menu to *image2m* and the Blending pop-up menu to *Add* mode. Set *Scale* to 1.4 and *Offset* to 0. Click *OK* to add the images. With *comp1* still selected, repeat the *Apply _ Image* operation two more times to add *Source* files *image3m* and *image4m* to the *comp1* composite image. The final result is shown in Figure 7. This image has enhanced structure in the corona and shows details in both the inner and outer corona. Compare it to the initial images in Figures 1 and 6.

A lot of experimenting can be done to fine tune the appearance of the composite image. For instance, a different value for *Scale* can be used in the *Apply _ Image* dialog. This will control the contrast and dynamic range of the final composite. If more 'c' images are available, they can be included in the overall processing to increase the brightness range and resolution of the composite.

8. Variation on a Theme

In order to exaggerate the corona's detail even more, the following variation works well. Make a copy of *images4s* and call it *images4sx*. Add all the other 's' images to it using the *Apply _ Image* function (Scale = 1, Offset = 0). This produces an image containing the structure information present in all four 'c' photographs (Figure 8). Duplicate the longest exposure 'c' image (i.e. - *image4c*) and name it *image4mx*. Use the *Apply _ Image* function to multiply *image4mx* by *image4sx*. Duplicate the shortest exposure 'm' image (i.e. - *image1m*) and call it *comp2*. Use the *Apply _ Image* function (*Scale* = 1.4, *Offset* = 0) to add

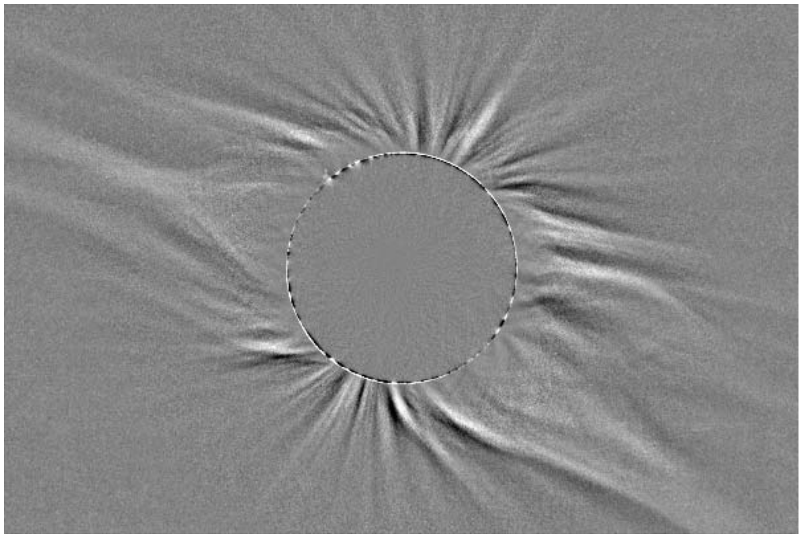

Figure 8. The coronal detail visible in the composite image (Figure 7) can be increased further. The first step is to use the 'Apply Image' dialog box to add all four subtraction images (from Figure 6) together. This produces an image containing the structure information present in all four of the original photographs.

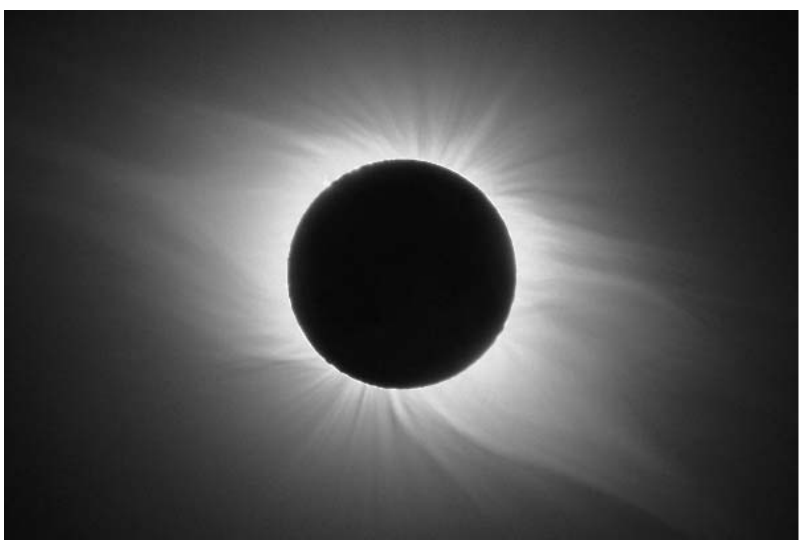

Figure 9. The enhanced composite is produced by first multiplying the subtraction image in Figure 8 with the 1/2 second original eclipse image. This final image is now added to the 'm' (multiply) images for the 1/125, 1/30 and 1/8 second exposures.

image2m, image3m and *image4mx* to *comp2* (Figure 9). The difference between this composite and the first one (i.e. - *comp1*) is that it uses *image4mx* instead of *image4m*.

Recent improvements in computer performance and technology coupled with decreasing costs have made sophisticated image processing available to both professional and amateur astronomers. Digital compositing presents a powerful new enhancement procedure, which can produce photographs of the corona that closely resemble its naked eye appearance. The 1999 total eclipse offers the chance to make additional improvements on this promising new technique. Examples of the 1999 eclipse as processed using these digital compositing techniques may be seen at:
http://www.MrEclipse.com/TSE99reports/TSE99Espenak.html.

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