Lab 7: Deep Sky Imaging
*(Due: 2008 Apr 28)*

**Pretty Pictures**

The taking of “deep sky” images refers to the imaging of non-solar-system, non-stellar objects, which might, however, include clusters of stars, gas and dust clouds (nebulae), galaxies, or other extended objects. The basic technique for taking the images is really no different than those you have already mastered—take many images, calibrate them (bias, dark, and flat), and combine them. The goal, however, is purely esthetic—the making of “pretty pictures.” It is not that there is no scientific value in the resulting image, but the final image will be adjusted in non-linear ways that make the brightness (and possibly color) variations no longer accurate. Instead, the goal is to bring out subtle detail that the eye is good at discerning, especially with the help of computer sharpening and enhancement algorithms. Once the details are found, the scientist then goes back to the original, non-enhanced image to make photometric or astrometric measurements of scientific value.

**Transfer Functions**

The first and simplest enhancement is the manipulation of the transfer function. It was noted that CCD cameras are good at linear measurement of photons. That is, if one object produces twice as many photons per pixel as another, it will appear in a CCD image as twice as bright (twice the amplitude). But you have already seen one problem with this when you were working with the images of Saturn’s moons. The root problem is a mismatch between the range of brightness the eye can see—typically about 256 different shades of brightness—and the range that the CCD can measure (in our 16-bit camera it is \(2^{16} = 65536\) levels). When you manipulated the high level in Astrometrica (set it to 5000 or 10000), you were changing the part of the 65536 possible values that were mapped into the 256 levels that the computer can display, as shown in Figure 1. Panel a) shows the default setting for Astrometrica, where the range of brightness is from 270 to 449. Panel b) shows the image after setting the range to 5000. As you found, the moons are now visible, but the faint stars and background have gone black.

The lower value in the range (270 in panel a), is called the **black level**, which means that pixels having this value or lower are black on the screen. The upper value in the range (449 in panel a), is called the **white level**, and all pixels having that value or higher are colored white. Setting the black and white levels is a simple example of a general concept called the **transfer function**. In mathematical terms, consider the input pixel range of the image (0-65535) as \(i\), and the output pixel range of the computer screen (0-255) as \(o\). Then the transfer function is:

\[
o = \begin{cases} 
0; & 0 < i \leq 270 \\
255* (i - 270)/(449 - 270); & 270 < i \leq 449 \\
255; & 449 < i \leq 65535
\end{cases}
\]
This function is called a piece-wise linear function, and is shown graphically in Figure 2, below. The input brightness values are scaled linearly, but only for values between 270 and 449. This is not good for displaying the moons, because they have brightnesses somewhere around 3000, and the halo around Saturn is brighter than 500, so this transfer function makes everything around Saturn white. When we set the white level to 5000, we have the transfer function shown in Figure 3. It is still a piece-wise linear function, but now the range of the linear scale is widened and the moons and their background are in the output range so that they appear other than white. Notice that the slope of the function in Fig. 2 is steeper than in Fig. 3. This is a general rule—the steeper the transfer function, the more contrast one sees in the image.

Finally, Figure 4 shows the transfer function corresponding to logarithmic scaling, but with a black level still set at 270. The steep part of the curve occurs at input values 270 to about 400, so input values in this range show a lot of contrast. For higher input values (greater than a few thousand), the slope of the function becomes less steep, so there is much less contrast in the image for these values.
Figure 2: Transfer function graph for Figure 1a. The black level is 270, and the white level is 449.

Figure 3: Transfer function graph for Figure 1b. It is still piece-wise linear, but the white level is set to 5000, so the linear range now extends to input values of 5000.
Transfer functions can be of any shape. Common ones are logarithmic \((o = \log i)\), square-root \((o = i^{1/2})\), or more generally a gamma function \((o = i^\gamma)\)—\(\gamma = 0.5\) is the same as a square-root function. You may have heard of the term gamma correction (see [http://en.wikipedia.org/wiki/Gamma_correction](http://en.wikipedia.org/wiki/Gamma_correction)). In MaxIm DL, or other image processing software, you can even draw your own function by hand, so literally any transfer function is possible. However, it is rarely useful to use complicated transfer functions. For the purposes of this lab, we will stick with logarithmic transfer functions.

**Image Smoothing and Sharpening**

Once you have set the transfer function as you like it, you may find that (1) the brighter parts of the image have a “soft,” unfocused appearance, and (2) the background and fainter parts of the image is noisy. Let’s look at these two cases one at a time.

**Sharpening:** One can sharpen, or enhance, the brighter parts of the image by several standard techniques that we will not go into in detail. Some well-known techniques are “unsharp-masking,” “fourier filtering,” and “digital development.” MaxIm DL has all of these, but we will use the tools in Photoshop instead, simply because they are easier to
use. The purpose of these tools is the same, to increase the contrast of smaller spatial scales (higher spatial frequencies) while decreasing the contrast, or removing entirely, the larger spatial scales. In Photoshop, we will use the “Sharpen,” or “Smart Sharpen” filters. In general, it is easy to overdo sharpening and make the image look unnatural, so it should be applied in moderation. Always sharpen the bright (high signal-to-noise) parts of the image, but not the fainter, noisy parts of the image.

**Smoothing:** Smoothing is just the opposite of sharpening, but should be applied typically to the fainter parts of the image. Remember, wherever the transfer function is steep, as we noted before, the contrast is enhanced. For the logarithmic function, the steepest part is in the faintest part of the image, which is where the signal-to-noise ratio is smallest, so the noise is enhanced. For a visually pleasing image, you will want to smooth the noise. Again, however, too much smoothing makes the image look unnatural, so apply it carefully and in moderation. Common tools for smoothing are based on averaging, taking the median, or convolution. In Photoshop, we will use tools from the Blur menu, such as “Smart Blur” or “Surface Blur.”

**Planning Observations**

Before coming to class, you should use Cartes du Ciel or other software to see what deep sky objects are available after 8 pm on 19 April. Please choose an object before coming to class, and write down some relevant information in your log book (type of object, designation of object, constellation that it is in, when it rises, culminates, and sets, its altitude and both its magnitude and surface brightness). Make sure you set the time in your software to the appropriate date and time (i.e. 21:00 on 19 April), otherwise some of the information such as times and altitude will not be correct. Figure 5 shows an example—the so-called antenna galaxies—NGC 4038. To help in choosing an object that you think will be interesting to make an image of, search on the web for some candidate objects, using, for example, google image.

The spring of the year is “galaxy season” because there are many galaxies and galaxy clusters in the spring sky. However, from downtown Newark the sky is bright, so the fainter galaxies are going to be difficult to image. Stick with brighter ones, or with star clusters. The best nebulae (gas and dust clouds) are in the winter and summer (because they are found near the plane of the Milky Way), so there are not many to choose from in springtime. Make sure that your chosen object is not above 70 degrees elevation, however, because the telescope cannot point that high without the camera hitting the mount. The best “seeing” will be between 40 and 70 degrees elevation, although you should get good data down to 25 or 30 degrees.

Some nice objects to consider are any of the Messier objects, especially M64, M88, M101, globular clusters M3 or M53, and NGC objects NGC 4565, NGC 3521. There are also some nice open clusters, such as M35, M36, and M38. One nebula you might try is the Eskimo nebula (NGC 2392). Typing Spring Deep Sky Objects in google will also net you some lists of good objects to choose from.
Figure 5: Example of finding a potential deep-sky object. Note in your log book the designation (NGC 4038, magnitude (10.3), surface brightness (13.1), type of object (interacting spiral galaxies), constellation (Corvus), rise, culmination and set time, and altitude (23.5 degrees). This object may be too low in the sky to be a good target.

Taking the Observations

This section assumes that it is clear on 19 April. If not, you should instead use some data that are already taken for you and proceed to the next section. It is really important, however, that everyone take their own data if at all possible, since it will give you great satisfaction to produce a pleasing image that you took for yourself.

Deep sky objects generally benefit from very long total exposure times. However, with 6 students each trying to observe an object in, say, 2-3 hours, we are limited to 20-30 minutes per object. Plan to take 50 images of 20 s each. Including download time, this will take about 20 minutes.

This procedure assumes that the telescope has been pointed at a focus star, the camera is cooled to its operating temperature and the telescope is focused. First find your object in Cartes du Ciel and point the telescope to it. Connect the telescope in MaxIm DL, so that you can adjust the telescope pointing from MaxIm DL. Take a test exposure of 20 s and verify the pointing. You should see your object in a single exposure. If not, it is too
faint, or else the telescope is not pointed at the correct object. If necessary, center the object by right clicking on it in the image, and selecting “Point Telescope Here.” Once you are certain of the pointing and the object is centered, begin a sequence of 50 images of 20 s each, using the luminance filter.

Do not just leave after your images are taken. We still have to take a series of Bias, Dark, and Flat frames, at least 10 of each. If the temperature was −25°C, you might be able to skip the bias and dark frames, and use some from a previous night. But the Flat frames are needed.

**Analysis**

To analyze the data, you will first do the Set Calibration as in Lab 5, to Auto-Generate the calibration file selection, and then create master frames. Then use the File/Batch Save and Convert menu item to calibrate all of the files and transfer them to a “Calibrated” directory. Then combine the images, being careful to throw out any that are spoiled by telescope movement, airplanes, or other problems. Save the combined image as a 16-bit FITS file, for later use in **IDL** and **Photoshop**. Write in your log book (and in your report) how many images you had to throw out, and how many you kept, as well as the total exposure (sum of exposures of the images you kept).

The image so far is still scaled linearly, so the next step is to apply a logarithmic transfer function. We will use **IDL** to do this. This part of the analysis is really a matter of taste to some extent, and is art more than science. The goal is to set the black and white level appropriately and scale the values in between using a logarithmic function. In **IDL**, read your image using READFITS:

```idl
img = readfits(dialog_pickfile())
```

choosing the combined-image FIT file you created and saved in **MaxIm DL**. Next, make a plot of a single line of the image in order to determine the rough background level, i.e.

```idl
plot, img[*, 500], yran=[0, 2000]
```

This should give you a horizontal profile of the brightness of your image, from which you can estimate the background level by reading it off the y-axis of the graph. You want to set the black level somewhat lower than this, perhaps 50 lower. Say that your background level is 230. Then use a black level of 180. Display the image, using your black level (180 in this example), scaling the input logarithmically (alog10 function):

```idl
tv, bytscl(alog10((img-180)>10<60000))
```

The meaning of the >10 in the above command is that, after subtracting the black level of 180, a further black level of 10 was applied. The overall black level can be considered 190 (180 + 10) in this case. If you want to see the entire image (recommended), maximize the window and reissue the above command to redisplay the image. Figure 6a shows the Eskimo nebula with this set of numbers.

You should now see the image displayed with a “pretty good” transfer function, but the object may still be too faint or not contrasty enough. In that case, try lowering the white level (60000). Figure 6b shows the result of the following command:

```idl
tv, bytscl(alog10((img-180)>10<6000))
```

where the white level was dropped to 6000. This leaves the background a little too bright, so I further adjusted the black level by increasing the 10 to 30, i.e.

```idl
tv, bytscl(alog10((img-180)>30<6000))
```
as shown in Figure 6c.

**Figure 6:** Different scalings for the image Eskimo-L.fit. All are displayed using a logarithmic transfer function. The image in *a*) uses a white level of 60000. In *b*), the white level was dropped to 6000. Now the background is too gray, so to make it darker, in *c*) the lower limit was raised from 10 to 30.

In *d*), the image in *c*) is processed using Smart Sharpen in *Photoshop*. This enhances the contrast of the smaller details within the nebula.
Once you are happy with your image (after adjusting the three numbers above—go ahead and play with the numbers to try different scalings), save the image as a bitmap image by typing the following commands:

\[
tvlct,/get,r,g,b
\]
\[
write\_bmp,<\text{outfile}>,\text{bytscl}\{\text{alog10}((\text{img}-180)>30<6000}\},r,g,b
\]

where <\text{outfile}> is the name of the file you want to save, in quotes. Make sure you use the extension \text{.bmp} for the file, since that is the type of file that WRITE\_BMP creates.

For this example, I might use the command:

\[
write\_bmp,'Eskimo-L.bmp',\text{bytscl}\{\text{alog10}((\text{img}-180)>30<6000)\},r,g,b
\]

Write down in your log book the values you used for the two black level values and the white level. Also write down your filename.

Finally, read the bitmap (.bmp) file into Photoshop for final processing. There, you can further adjust the black and white levels and the transfer function using the Image/Adjustments/Levels… menu item. You can also sharpen the image, using the Filter/Sharpen/Smart Sharpen menu item. Examples of typical adjustments will be shown in class. You may also colorize the image, add labels, and so on. The image in Figure 6d shows the application of a small amount of Smart Sharpen. Save the image for the web, and we will post the results on the astronomy web page. Write up some lines of text that give the total exposure, the telescope and camera used, etc. Here is an example (the text below the image): \url{http://www.robgendlerastropics.com/M81NM.html}. We will add your lines of text to the web page also.

In your report, write a short paragraph about your object—what is its history? Why is it interesting. See an example here: \url{http://www.robgendlerastropics.com/M81text.html}.

**Conclusion**

The adjustments and manipulations you do on your image have the purpose of bringing out features that the eye and brain can interpret, which may not have been visible in the raw images. The result can be considered more art than science, and the goal is partly to make an image that is esthetically pleasing. Once a feature is identified, the scientist will go back to the linear, scientifically valid data when photometric measurements are needed. But everyone, even scientists, appreciates a pretty picture.

**Bulletized Synopsis**

**Purpose:** Take deep sky images and make a “pretty picture.”

- Plan for observation of deep sky object, and write down information about the object. Give some consideration to its altitude at the time of observation.
- Take a series of about 50 images of 20 s each, calibrate for Bias, Dark, and Flat.
- Combine the images to create a single image, throwing out images that are spoiled due to telescope motion or other problems.
- Use IDL to read the fits file, apply a logarithmic transfer function, so that the image looks pleasing to the eye, and save the result as a bitmap file.
- Use Photoshop to do additional adjustments, sharpening, or other enhancement, if necessary or desirable. Write some text to display with the final image and report.