CCD Image Processing on M106

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1 Introduction

When we look at an image of a distant object, such as M106, M104, or M16, we need a way to capture the image data. Starting with photographic plates back in the 1800s, astronomers today use CCD or CMOS imaging. These work entirely different from the photographic plates used in the 1800s, as CCDs capture photons emitted by the object and its surroundings which are then converted to electrons. For this report, we will focus on processing CCD images, with M106 being the object that we observe and process.

2 How Do CCDs Work?

2.1 Physical Process of Capturing Data

CCDs are constructed in a grid system, with every cell of the grid representing a pixel. These cells move down each column one by one until it hits the bottom of the CCD, like a game of Plinko, where there is a read-out register, and pixel by pixel they are fed through an output node. In the output node, each pixel is converted to a voltage and is then amplified to make it easier to read. Next, the cell is passed through an analog to digital converter(ADU) which then converts the voltage into a number. This number that this step produces is what we use to process the image. A low value will represent the darker pixels of the image, and a high value will represent a brighter pixel. How are these numbers determined? These come from the exposure of the image. The more photons hit the cell in a CCD, the higher the value will be.

3 Processing Image Data

When processing the data, you can not just output the image and have a high resolution image of the object you observed. When collecting the data, the CCD is not just capturing the object but also everything in its area. This introduces the problem of a bias signal in the picture.

$$C = \frac{(B_f + B_s + \epsilon N_\gamma)}{g} \tag{1}$$

When the ADU outputs a value it not only represents the object we are observing but also getting data from its surroundings. C represents the value given from the ADU, and from Equation 1 we can observe that it can be broken into 3 different variables, two of which can be identified as bias that we can account for. B_f represents the floating bias that varies over time. B_s represents the static bias which is constant over time but varies from pixel to pixel.

$$B = \frac{B_f + B_\gamma}{g} \tag{2}$$

The total Bias contribution to the CCD image can be accounted for in just two variables. This allows us to remove any offsets given and allowing us to calibrate the image without the interference of a bias offset. Also note how all these terms are divided by g, this is from when we are making measurements on a CCD, we are converting electrons into counts, and g is the converting factor.

The third term in the equation is N_γ, this represents the incident photons. This variable is important as these are the values that represent the photons captured by the CCD. We need to remove the bias first before we can fully process our image.

3.1 Removing Overscan Data (B_f)

Overscan is an additional region in the CCD image that records extra pixel values past the active imaging area. This allows us to use the overscan region as a reference for B_f. This overscan region records the fluctuations over time which can contribute to the temperature changes in the electronics to the volatage fluctuations in the CCD. You must remove the overscan in each image as this helps remove one of the Bias in the image.

3.2 Master Bias (B_s)

When we take a zero second exposure with the shutter closed, we notice that although it is taking a completely dark photo the CCD is processing non-zero data from the pixels. To account for this, we take multiple bias exposures; in this case we took 25 frames, removed the overscan from each frame, combined each frame, get the average of the combined frames, and that would get you your master bias frame. Creating a master bias frame is essential to remove the B_s or static bias from the data. If we do not remove the static bias from the frame then our image will be artificially elevated that will ultimately affect the brightness measurements taken further down the line. As shown in Figure 1, the creation of a master bias should be completely black. The artifacts in this image such as the vertical white band are due to bad columns in the sensors. These will eventually be filtered out as we process the image.

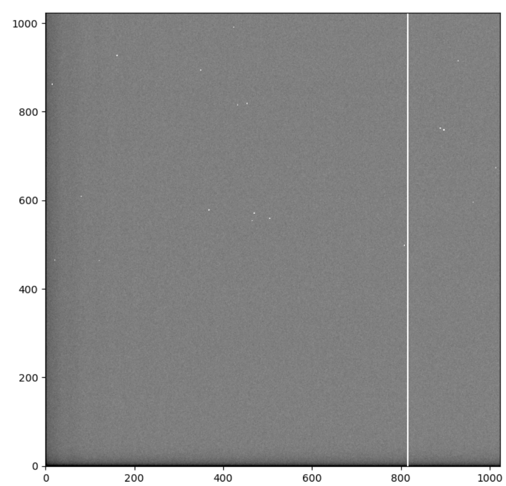

Figure 1: Master Bias Frame.

3.3 Master Flat Field Calibration Image

A master flat field image is crucial when it comes to CCD image calibration because it corrects for pixel-pixel variations. Without the flat-field corrections, there may be some artifacts on your processed image. One notable artifact that appears when the flat is not done correctly would be dark rings or donuts. The creation of a master flat field image is similar to that of a master bias frame, with there being notable differences in the process. From the master bias we took a zero second exposure with the shutter off to get B_s, for the flat-field image we need to take an exposure image of a uniform light source. For this we took various exposure shots at sunset just as it was getting dark. Not only did we take measurements from different exposure times, but we also used 3 different filters, R-Band, B-Band, and the V-Band. Each filter represented a different wavelength on RGB, R-band representing red, B-band representing Blue, and V-Band representing green. This means that we will have a flat-field image for each filter we used. We also need to subtract the master bias to each of the flat-field images to account for the B_s in the image. After we subtract the master bias frame we need to scale the image so its median would result around 1.

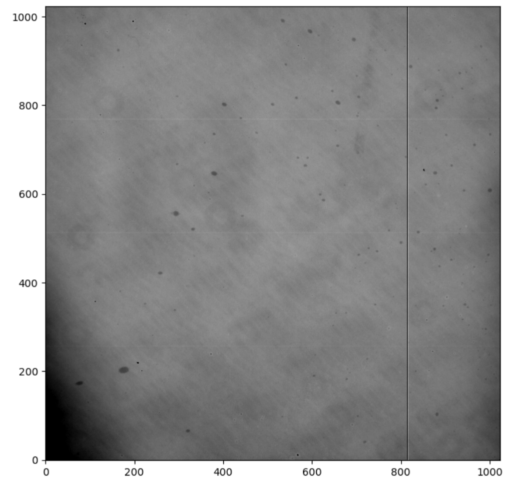

Figure 2: Flat Image from the B-Band

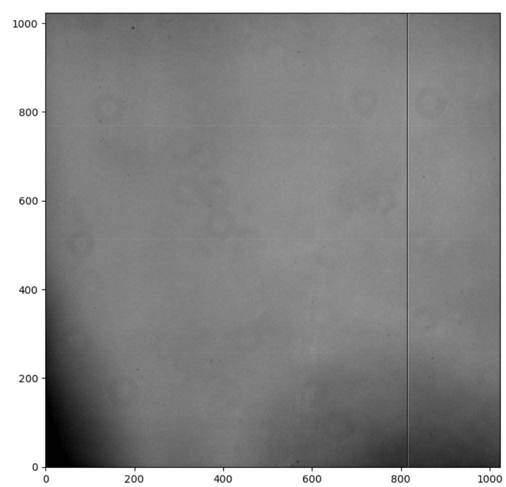

Figure 3: Flat Image from the R-Band

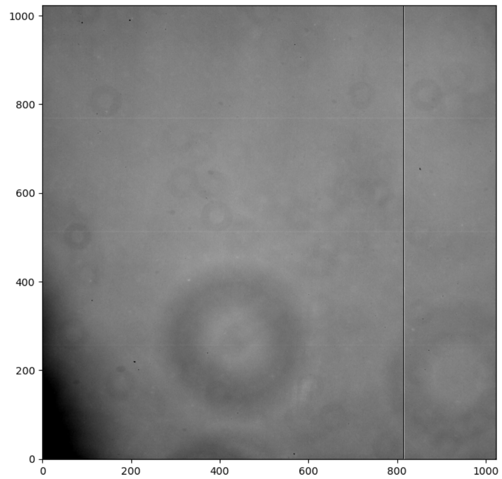

Figure 4: Flat Image from the V-Band

3.4 Time to Process

Now that we have the master bias frame and the flat-field calibration images, we are now ready to process the image. The process in which we proceed is represented in Equation 3.

$$P = \frac{D - B_s}{f} \tag{3}$$

D represents the raw data of our image after the overscan has already been removed. This ensures that we account for the B_f present in all the images. We then take D and subtract it to B_s as this removes the static bias present in the data. f represents the flat-field calibration image. We divide f over $D - B_s$ to account for the pixel-to-pixel variations from frame to frame. Recall back in section 3.3 where we discussed scaling the flat-field image to 1, this is the reason why. One thing to remember is that we took a flat-field calibration image in 3 different filter bands, so we would need to process the image in each of the bands. As you can see in Figures 5, 7, and 6, the image is processed from each of the separate filters used. In the next step, we will combine the images to make a 3 color image.

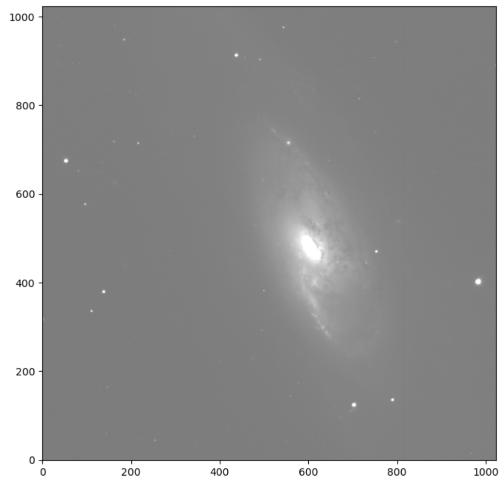

Figure 5: M106 Processed from the R-Band

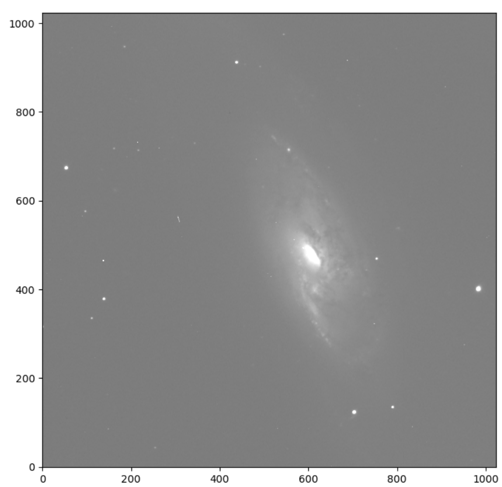

Figure 6: M106 Processed from the V-Band

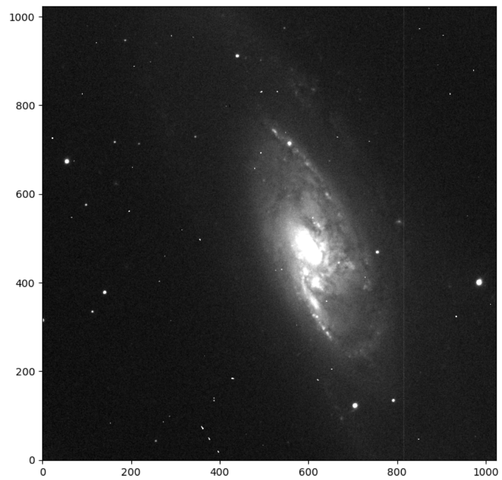

Figure 7: M106 Processed from the B-Band

3.5 Combining the Images

Since the processed images were taken in different filters of the RGB spectrum, we can combine these images, creating a colored image. Its not as simple as combining the images in one go, and we have the final form of the image. Before we can combine the images together, we must first identify the min and max values in each processed band. We need to identify these values to cap the values in the image, to control the brightness of the image so that everything looks clear. To do this, we will start by determining the average background value in the image. We do this to identify the typical value of the pixels that do not emit light. Once the mean μ is found, we have to find the standard deviation σ. The standard deviation is important to find, as this tells us how much the data is spread out. Once the standard deviation and mean are found, we can identify the min and max values.

$$min = \mu - \sigma \tag{4}$$

$$max = \mu + 6\sigma \tag{5}$$

The equations used to identify the min and max values can be seen in Equations 4, and 5. We multiply σ by six so that we can keep the data six deviations from the mean. We can go further to keep a larger set of numbers, but that would affect the quality of the final image. And now, we can see the final processed image of M106 in Figure 8. Isnt it a beauty?

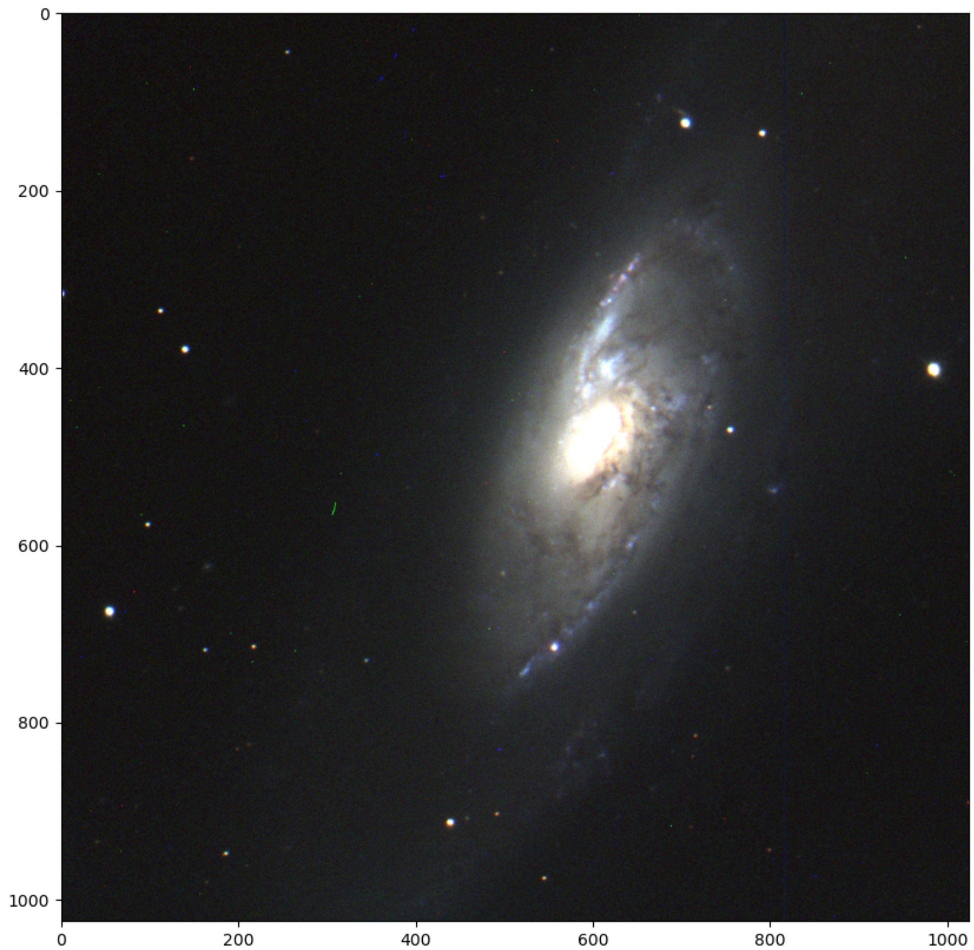

Figure 8: Final Processed Image of M106

4 Conclusion

Processing a CCD image was not an easy task, but getting the final image of M106 was well worth the effort. To understand that we processed an image from a device that collects photons, which are then converted into voltage values, eventually we are able to get the image as seen in Figure 8 is very enlightening. Observing a distant object such as M106 which is appx. 24 million light years away, and to get such a clear image is an amazing feat in engineering and astronomy.

References

[1] YouTube, “Image Processing - Video by Robert Quimby,” Available: https://www.youtube.com/watch?v=I86Ov1W9aEY&t=876s, Accessed: March 10, 2025.