THE USEFULNESS OF FLAT FIELD IMAGES

DOES TIME MATTER?

by

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ABSTRACT

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Senior Thesis

CCDs are a relatively recent invention that has strongly changed astronomy. Previous methods were either logarithmic or incapable of observing multiple stars simultaneously, and always had comparatively low quantum efficiencies (QE). CCDs, despite having many faults, are a linear detection system that utilizes pixels and can thus observe many stars simultaneously, while also having extremely high QEs, ranging from over 60% to over 90% at the peak wavelength, depending on the specific chip. A major problem that does arise from CCDs is that they require calibration images to be taken in order to generate accurate, repeatable data. Perhaps the most difficult of these calibration frames is the flat field. It is not uncommon to not obtain flat fields on a given night due to a variety of reasons. The focus of this thesis was to determine how detrimental it is to use flat fields from other nights. The effect of the time between observation and flat field was also examined.

ACKNOWLEDGMENTS

I wish to thank Jake Albretsen for giving me the idea for this project. I also want to acknowledge the following individuals for making their flat field observations available for this project: Dr. Eric Hintz, Tabitha Bush, Kathleen Moncreiff, David Broadbent, and Roo Phillips. Finally I wish to express appreciation to my wife for making me actually write this thesis.

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Chapter 1

Introduction

Astronomy started as a science where observations were made with the human eye. The eye has a number of drawbacks; 1) it is none linear, 2) each observers detector is different, and 3) there is no permanent image created. With the advent of photographic emulsions astronomers had permanent images, but photographic plates had problems of their own. With the introduction of the photomultiplier, astronomy moved into an era of electronically measuring the photons from the heavens. Again photomultipliers presented a new set of problems. The current detector of choice in astronomy is the charge coupled device or the CCD. These have solved some of the problem inherent in the other systems, but present a number of concerns of their own. In this thesis a number of these concerns will be addressed to maximize the quality of the data generated to astronomical research.

1.1 Photographic Plates

Photography was developed as a way to record data and quantify astronomy. We now had permanent images recorded and could take time exposures to examine fainter objects. Astronomy related photography thus opened the door for accurate scientific analysis of the stars, and photographic plates are a more modern variant of photography in astronomy. Photographic plates had the obvious advantage over visual observations of recording a image that could be examined many times. They also had the advantage of being able to render an entire star field at the same time, not merely collect photons from a single star, such as is done with a photomultiplier. Another important advantage was that they had extremely high resolution, since they had no individual pixels. However, photographic plates had a number of disadvantages which include nonlinearities, storage, preparation, and QE. Photographic plates only respond linearly to light over a given range. Bright and faint objects are not recorded linearly. Another complication is the difficulties of getting a plate from the refrigerator to the telescope and inserting it at the focal point of the telescope without either exposing or breaking it, as well as the incredibly low quantum efficiencies (QE), which could be raised over 10% at peak wavelengths only by baking the plates after covering them with a special solution and then using them within 12 hours of baking, while refrigerating between baking and use.

1.2 Photomultipliers

Photomultipliers came into astronomy considerably later than photographic plates, reaching their heyday of usage in the 1980s and early 1990s, and they actually did have a linear response to light, making precise calculations much easier. They also had much higher QEs than photographic plates, and were in general easier to manage. They had two significant problems. As previously mentioned they could only image one star at a time, making variable star work or photometry difficult and inconvenient, since every time a comparison image of a standard star was required, the telescope had to be moved to the comparison star and back to the object of study. The second important failing was that photomultipliers, due to their internal mechanics could only process one photon at a time, so that multiple photon strikes were counted as one, and any photon counts received while the last hit was being processed were ignored. This was not a significant problem for low intensity stars, but it was a significant one for brighter stars. Besides being able to only work on one star at a time, the other problems could be overcome and per observations the photomultiplier is still the best detector.

1.3 Charge Coupled Devices

CCDs have now become the detectors of choice for a large fraction of astronomical research. However, CCDs are not with out their problems. They are fairly straightforward devices, being an array of pixels, or "wells", that when struck by a photon release an electron which is then stored in the well and counted as a photon strike. This array of brightness measurements can then be turned into an image that can be analyzed in a variety of ways. Overall, CCDs are far better for most optical and near-optical stellar observations, since they combine most of the good qualities of the above devices, while eliminating most of the problems mentioned above. CCDs do not have a time delay for counting photons, they have linear responses, they can image multiple stars simultaneously, and they can have incredibly high QEs. These QEs commonly are over 60%, while many chips breach 70%, and some even go over 90% QE. The biggest problem with CCDs is dealing with the electronic noise they generate, because any extra electrons in the pixels can be easily mistaken for photons. In addition, each pixel can have slightly different characteristics for which adjustments must be made. To compensate for this noise, three varieties of calibration images are commonly taken for normal optical observations: zeros, darks, and flats. Of primary interest in this thesis will be the flat field frames.

Chapter 2

Background

2.1 Types of Calibration Images

2.1.1 Zero Frames

Zeros, also called bias frames, are exposures made for zero time, with the shutter closed. A sample bias frame is shown in Figure 2.1. When the electronics of a CCD are energized a number of counts appear in each pixel. This is purely from the electronics and not from any astronomical sources and they represent a minimum value for each pixel that must be subtracted. They are the first frames applied to the star images, (also known as "object frames" or just "objects") and are also applied to all other calibration images. Depending on the CCD camera and the temperature they can make only minor differences to the final image, or remove significant patterns. They can also show the existence of "hot" pixels that must be accounted for in any reduction.

2.1.2 Dark Frames

Darks are a slightly more complex calibration image. Their purpose is to detect the "dark current" that flows through all CCD chips. A sample dark frame is shown in Figure 2.2. This "dark current" is simply normal electronic noise that leaves electrons in the various pixels over time. Darks are highly sensitive to both the length of exposure and the temperature of the chip. A major issue with exposing darks is that the electrons left from the dark current do not necessarily increase linearly with time, but may increase according to some other function. Thus, darks are ideally taken for the same length of time as the actual image, to minimize any variability from different times of exposure. Also, since darks are so temperature

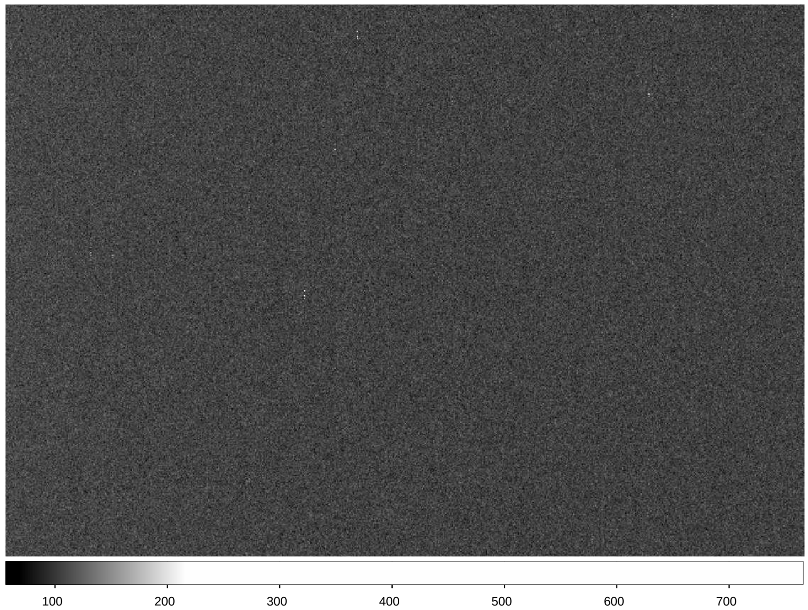


Figure 2.1: This is a standard zero, or bias, frame. It generally makes no visible difference in the images to which it is applied.

sensitive, different temperatures for darks and actual data frames ("objects") will be important unless the chip is being run at cyrogenic temperatures.

2.1.3 Flat Field Frames

The third type of calibration image is a flat field frame, or "flats." This image is used to find how the different pixels of the CCD respond to the same brightness and color of light. In order to provide exposure to light of an even intensity and color across the CCD, flats at the Orson Pratt Observatory at Brigham Young University (BYU) are usually taken pointing high in the eastern sky in the first half hour after sunset or pointing to the western sky in the last half hour before dawn. For whatever reason, the different pixels do not respond identically to light, but there are instead distinct patterns visible on every chip due to the different responses. Most CCDs show some kind of pattern across the chip. The pattern can be very filters dependent as shown in Figures 2.3, 2.4, 2.5. In these figures flats for the Johnson B, V, and R

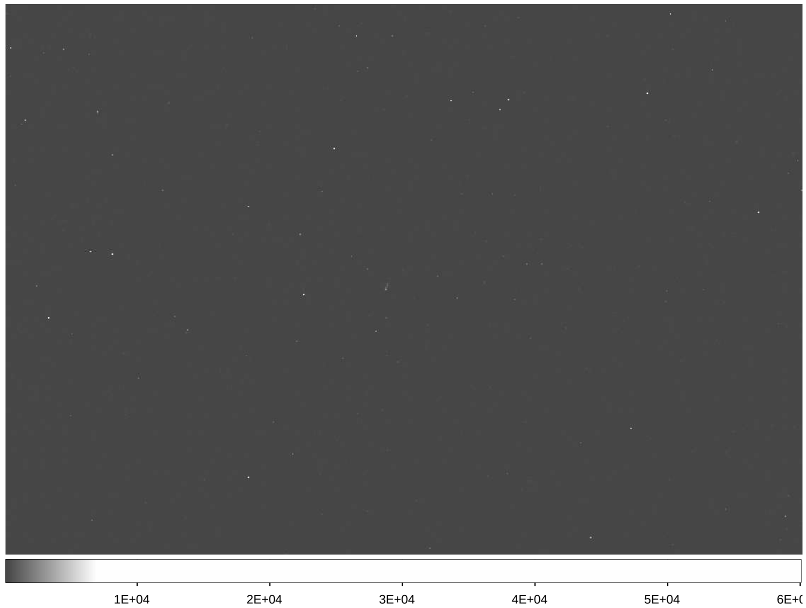


Figure 2.2: This is a typical dark for the 0.4-m David Derrick Telescope of the Orson Pratt Observatory. Darks can vary considerably based on temperature and exposure length.

taken with the CCD used on the David Derrick 0.4-m Telescope of the Orson Pratt Observatory are shown . It is important for astronomers to remove these patterns in the chip's response from the images before the magnitudes of the stars are determined.

2.2 The Usefulness of Flat Field Frames

This discussion on calibration images leads to some issues that have confronted astronomers since the CCD was introduced: how to properly use the various calibration images in processing their data, how often the calibration images need to be taken, and if they need to be taken at all. The mathematics of how to process the object frames with the calibration images is largely taken care of by the program IRAF (Image Reduction and Analysis Facility), so that is not currently a concern for most astronomers. What is a far bigger concern is if the calibration frames actually are useful, and how often they need to be taken to be useful. Many astronomers have many different procedures in this regard; some take flats daily, some weekly, some

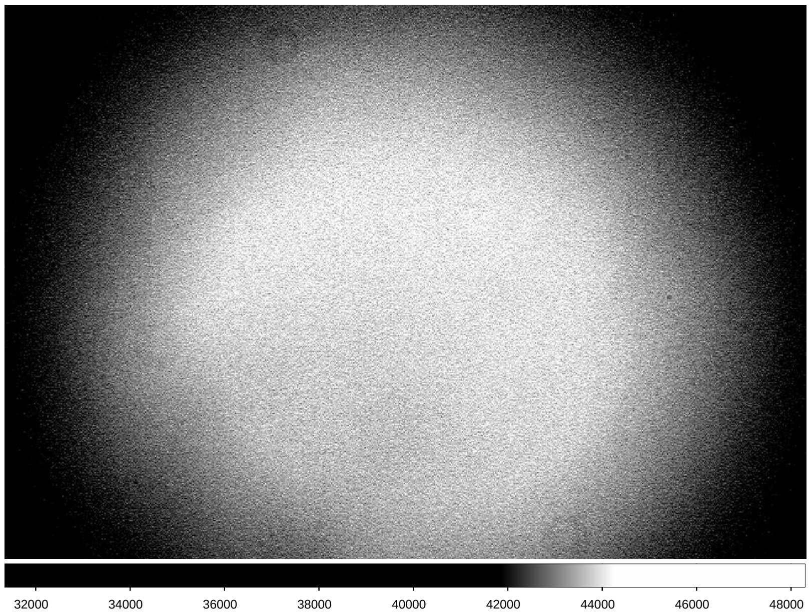


Figure 2.3: This is a generic B filter flat; notice the bright center and faded edges. This is the normal pattern seen with the CCD used for this project.

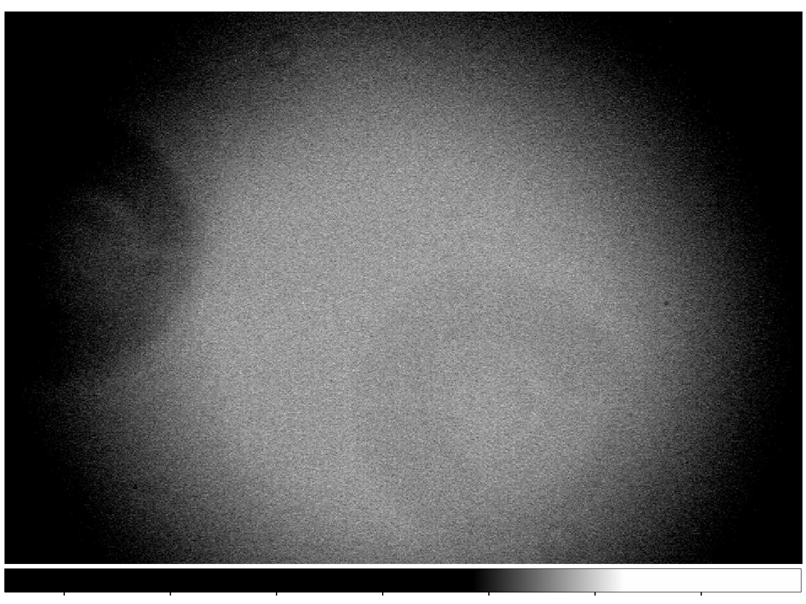


Figure 2.4: The V filter is the most commonly used filter at BYU, and so flats from the V filter were the easiest to obtain. For this reason there are more data points in the V filter as part of this analysis.

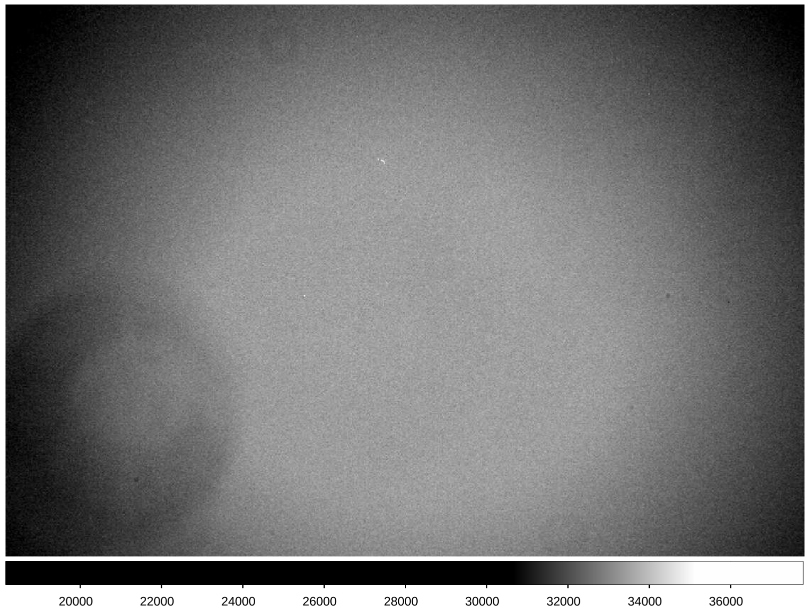


Figure 2.5: This flat was taken with the R filter. Note the circular marks off center; they could be dried water drops or dust on the mirrors, but since they do not appear in the B or V flats, they are associated with the R filter itself, not the CCD.

apparently never do, just trusting to luck that someone else will provide a useful calibration frame, and some think it is best to take flats at both morning and evening. Finally, as with most things in astronomy weather can play a role in obtaining calibration frames. If it is partly cloudy at the beginning of a night of observing then quality flat fields can not be obtained. Similar questions can be asked about the zeros and darks, but this project is focused primarily on the flats and the other frames will only be addressed in passing. With this in mind one must ask which flat fields can be used to calibrate frames from a night when no flats were obtained.

2.3 My Motivation

Because of the hap-hazard nature of the ability to obtain flat field frames, I started to wonder how often flats need to be taken, as well as if they are really necessary at all. Eventually, I decided to start a project that would determine how often flats are needed. Specifically, my project was to find out how many days can pass between when the flats are taken and when the object frames are taken in order to be useful, in order to create some sort of order and pattern in flat-taking. This will allow future projects to optimize there data by understanding problems that may arise from the procedure used to obtain calibration frames. Since it was related to my project, and involved comparatively little extra work, I also examined how applying zeros, darks, and flats each lowered an error curve for a field of stars.

Chapter 3

Procedure

3.1 Acquiring Data

When I first began planning this project, I had intended to only compare the combined flat field images, not the differential or apparent magnitudes of the stars. For that reason, I began taking flats, darks, and zeros in May, but did not obtain object frames. I took no data in late April or early May due to inclement weather, since data is usually not taken when the sky is overcast. I took flats on May 13, May 24, May 25, May 31, June 2, and June 6. I used flats and images taken on April 20, May 13, May 26, June 13, June 17, June 18. Thus I had flat field images from twelve nights over a two month spread. I hoped that this would be enough to show any variability based on the time between the data and the flat fields.

3.2 Flat Taking Methods

The flat fields and data were taken in standard Johnson B, V, and R filters, except for the flats taken on May 26, June 13, and June 17, which were only taken in the V filter. All flats were taken at dusk, usually in the first half hour after sunset. My flats were exposed for the longest time that would not overexpose them, and I monitored the photon counts on the flats, increasing the exposure times whenever the counts dropped too low (usually below either 10,000 or 15,000 counts in the brighter parts of the flat).

3.3 Choosing Comparison Nights

Once the data was taken, I began preparing to analyze the data. I had initially planned to use three nights as comparison nights, comparing the flats from all the other nights to the flats taken on those three, and I decided to pick one night at the beginning of the two month run, one in the middle, and one at the end. Once I realized, however, that finding the magnitudes of the stars would be necessary to analyze the data, I decided to “phot” (a command in IRAF that takes a reduced data frame and derives a magnitude for each selected star in the frame) the stars from each of the comparison nights with their own flats, assume that those magnitudes were correct and compare the magnitudes with those found when flats from other nights were used. This limited me to picking comparison nights that had been used to take actual object frames, not just flats. This meant that the nights at the beginning and end of the two months, April 20 and June 18, were ideal for comparison nights. I did not pick a night in the middle of the run at this time, since I wanted to see what initial results came out of using June 18 for a comparison night before going any further.

Chapter 4

Initial Analysis

4.1 Data Reduction

For my initial analysis, I used the images of SA 106, taken on June 18, and reduced them using flats from each day. By its nature, this project required that different flats be used on the same data, but I had to decide how to apply the darks and zeros. Usually, darks, flats and zeros are all taken on the same day and applied to the data from that day, but I had to decide if it would be best to apply the darks and zeros from the day of the data to all the flats (since those darks and zeros applied to the data) or to apply the darks and zeros from each night to the flats of the same night, since, the darks and zeros from each night would be needed to remove noise peculiar to that night from the flat. Each option had the possibility of allowing noise into the data, the first of allowing noise from the flats to affect the data and the second of allowing noise from the object frames themselves into the data. I chose the second option, because this project was meant to focus on the flats, so having all extraneous noise removed from the flats was more important than having all such noise removed from the data frames. Also, the possibility of noise from the object frames was a valid risk that can come from using flats of a different night.

4.2 IRAF

I then proceeded to reduce the images of SA 106 in IRAF, by applying my bias frames from June 18 to the darks of the same day, and then applying both to the flats of all three filters. Once the flats were reduced, with the noise picked up by the darks and zeros removed, I combined the flats of each filter into a single image, (following standard procedure for data reduction in IRAF), and applied them to the SA 106 images I had copied into the folder for each night. Thus, SA 106 was reduced

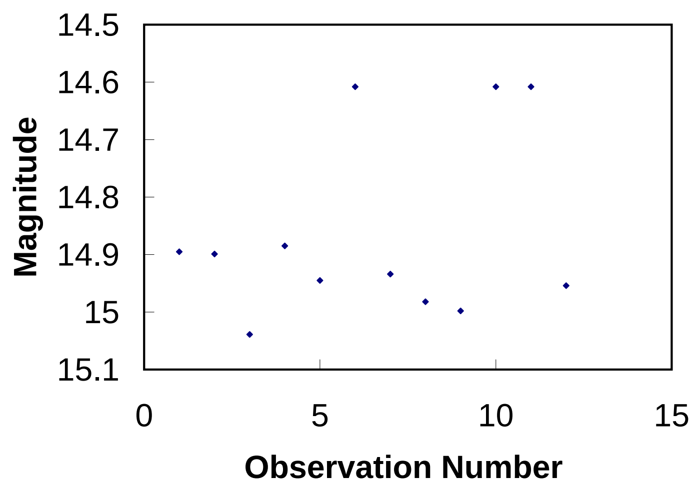


Figure 4.1: A plot of the B magnitude for one star measured after different calibration frames were used. The three high points are from calibration procedures that did not include flat field frames.

multiple times with a set of flats from each night. I then continued with the standard procedure in IRAF, using the "phot" command to obtain magnitudes for 8 of the stars in the image. I imported these magnitudes into EXCEL, and continued my preliminary analysis there.

4.3 Non-Differential Photometry

In Excel, I chose a single star and plotted its magnitude against the night the flat used on the data was taken on, using an arbitrarily assigned number to represent each flat night. This was to determine quickly is there was any variability in magnitude in the first place; if not, then it would be obvious that none of the variables present in the flats were important. The graph used a B filter frame, and included three days that did not have flats in the B filter, to see if the flats could be skipped entirely. In Figure 4.1 it is established that the flats do make a difference, and cannot be skipped without changing the calculated magnitude of the star as shown by the three high points. What it did not answer was if these magnitude changes were related to the time between the objects and the flats.

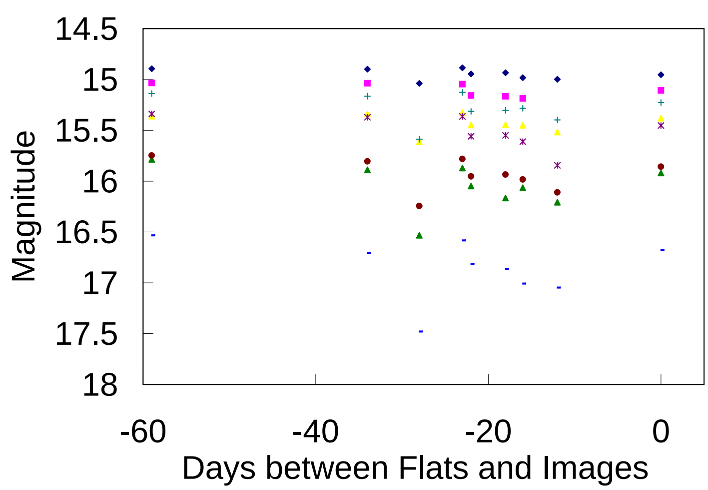


Figure 4.2: This graph shows all eight stars in the field of SA 106 with the magnitude plotted against the time elapsed between when the flats and the data were taken, with the negative values representing before the data and positive values would represent after the data, if it were used.

To determine if the different results in the magnitude were time related, I re-graphed all the stars which I had calculated magnitudes for in the B filter, this time graphing them against the time between the flats and object frames as shown in Figure 4.2. Since this graph was rather busy, and since its y-axis was too stretched to show minor changes in magnitude, I proceeded to make individual graphs for each star with an example plot for one star shown in Figure 4.3. This showed an odd pattern,

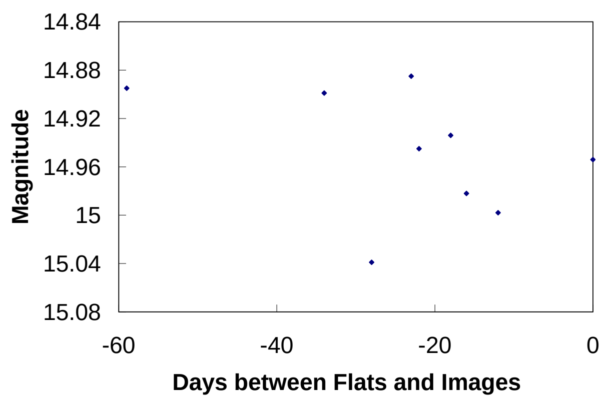


Figure 4.3: This uses the same star as Figure 4.1, but uses an actual time scale like Figure 4.2. It showed that while there was a difference in magnitude, there was no easily found function in time to describe the change and while there could possibly be a high-order polynomial equation that would describe the data, there are not enough data points to justify such a fit.

but not one that showed a function of time or had any immediately obvious reason to it. I then proceeded to make a table that showed the change in magnitude from flat to flat for the same star. I made this table for all three filters, unlike the graph which was done only for the B filter. To have a single, easily comparable number, I averaged the magnitude changes for each star with a given flat, once using absolute magnitudes and once ignoring the sign of the magnitude change from the original day. Both ways showed that some nights were much closer to the original night's data, but that they seemed to have no relation to time. There was no immediately obvious relationship between time and how closely the flats came to giving the same magnitude as the data processed with its own night's flats gave Figure 4.4. Also, nights whose flat yielded numbers close to the original did so in all filters, and those that gave strongly different numbers did so in all filters, implying that the filters are far less important than the other possible variables in the flats.

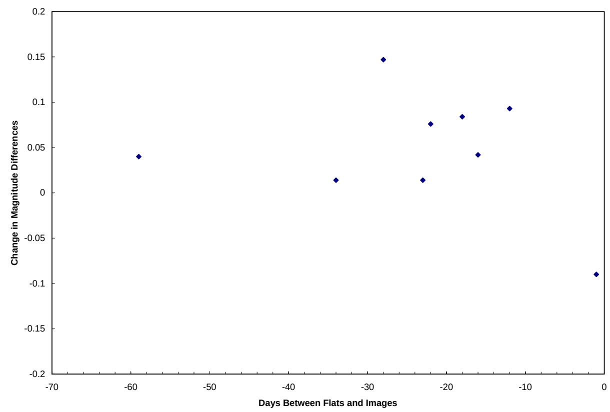


Figure 4.4: This plot shows the average change in the magnitude difference depending on the flat used, and again, the flats did not produce identical results, even for differential photometry, but there was not an obvious time dependent function to explain the pattern.

4.4 Differential Photometry

I decided to focus on differential photometry for the rest of my analysis, since that would be more useful to other research effort at BYU than an analysis based purely on full-sky photometry. This is particularly true for data taken from the campus observatory where completely photometric nights are rare. In full sky photometry we try to determine the apparent magnitude of the stars as precisely as possible, taking into account all events and effects that modify the star's brightness in any magnitude, using comparisons to stars with known magnitudes to calibrate our photometry. With differential photometry, the actual magnitude of the star is considered largely irrelevant, and the star's calculated magnitude is simply compared to the magnitude of other stars in the same frame (such comparisons were much more difficult before CCDs became popular), ideally to stars of constant magnitude. It does not matter if the magnitude of the standard star is known, so long as it is constant. The variable stars are then analyzed by how the difference of their magnitude minus the standard stars' magnitude changes. It was pointed out to me that it could be more meaningful and useful for me to see if the differential photometry changed from flat to flat. Having already established that the flats did yield different magnitudes, I had to agree that finding out if these different magnitudes mattered for differential photometry was the next logical act on my part. This approach took up the majority of my analysis and research.

Chapter 5

Further Analysis

My first act was simple: I needed to verify, quickly, whether or not the star's magnitude minus a standard star's magnitude changed based on which flat was used. I chose the brightest star, called "Star 1", as my standard star, and for every set of flats I subtracted the magnitude of each star from Star 1, then I found how much this difference changed compared to the difference in magnitudes found with the flats from the same day as the object frames. The change in the differences (ie, the difference between the magnitude of Star 1 minus the magnitude of "Star 2" using some day's flats minus the same using the flats from June 18th) was often no more than expected from noise, but was in some cases a very large effect, greater than 0.05 or even 0.1 magnitudes. Such cases tended to happen to the same flat on all days or all stars on a few days. In order to better analyze this, using more precise statistical methods, I turned to VARSTAR5.

5.1 VARSTAR5

VARSTAR5 is a program meant to take a series of magnitudes and create an "error curve", a plot that is "error per observation" vs magnitude. The magnitude in the graph is usually a comparative magnitude, where a standard star (or set of stars) is used as an initial magnitude and subtracted from the magnitude of the other stars in the curve. Creating an error curve like this is a standard technique in variable star photometry to identify if any stars have an unusually large amount of error for their magnitude, and thus identify potential variable stars. This is only a first test for potential variable stars (normally called "variables" for brevity), but if using flats that were not from the same night as the data give significantly different error curves, then it would make VARSTAR5 a considerably less useful mechanism for detecting variable stars. Therefore, running my data through VARSTAR5 multiple times, using different flats each time, was first, a good way to see if the different flats introduced extra error, and second, to see if using the various flats invalidated VARSTAR5 as a method for identifying variables. I quickly put the SA 106 data into VARSTAR5 but it gave only vague results, nothing that could be effectively analyzed, since it had only eight marked stars. For VARSTAR5 to work effectively, it needs many stars over a range of magnitudes. I chose to use the star field around the star AN Lyncis (AN Lyn) for further work with VARSTAR5, and the field had approximately 38 stars in the usable magnitude range, and AN Lyn. I proceeded to phot the frames of AN Lyn taken on April 20, using the same procedure as when I had photted the frames for SA 106 earlier. Once the AN Lyn frames had been photted separately for each day of flats in all filters, I used VARSTAR5 to find an the error curve of AN Lyn's field. I chose one star, AN Lyn, to be the standard in VARSTAR5 that created the error curve. I felt that it did not matter if this caused an unusually high error curve, because what mattered for this project was the change in error curves depending on the set of flats used, not how much error there was. I imported the data into Excel, and plotted an error per observation vs the magnitude graph for each set of flats, then I set about comparing them.

5.2 Error Curves

My original idea was to find where the "breakoff point" for each error curve was, and to measure how much that changed depending on the set of flats used. Although the entire curve should be exponential, most error curves have a region that is apparently flat, which then curves up exponentially. I zoomed in on my error curves in order to find where they went from flat to curved, but I found that this did not really happen with most of my curves, making a comparison by this method impossible. I therefore compared the shapes of the curves, looking for odd features such as stars below the curve, similar numbers and placements of flier points, similar maximum magnitudes, similar maximum errors, and also any clumps of stars.

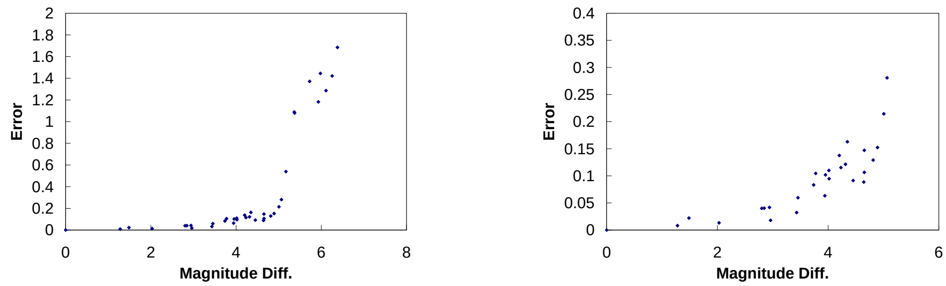


Figure 5.1: This was the error curve produced by calibrating image of AN Lyn in the V filter with the flats taken on the same day. All other V filter error curves were compared to this. The figure on the left is plotted at full range, while the one on the right is expanded to show greater detail for the brighter stars.

Sample error curves are shown in Figures 5.1, 5.2, 5.3. In all of this, I used the error curve derived from the June 18 flats as a standard, since the data was from June 18 and I chose to treat the flats intended for the data, as in earlier sections, as the standard. They would have been used and assumed to be correct, after all, had I not done this study. In addition to this qualitative assessment, I found the log of the magnitude differentials and errors, and plotted the log of the errors versus the log of the magnitude differentials. I found the slope of this graph for each day and plotted this slope versus the days elapsed from the flat to the data. This gave a more quantitative way of looking for relationships, and confirmed my qualitative comparison of the shapes. I found that flier points often expanded the scale of the graph to the point that it was hard to recognize similar shapes, so I often forced the axes of the graphs to be the same as the axes of the graphs derived from the original flats and data.

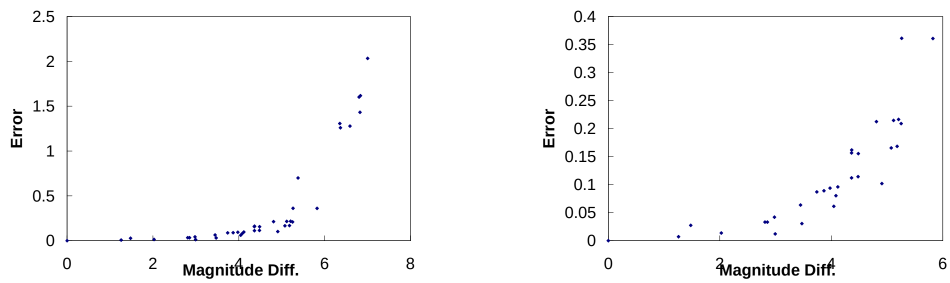


Figure 5.2: This error curve was for the V filter also, and used the flats taken on May 25. When compared to Figure 5.1, this plot has the same general shape; it begins to increase noticeably at about the same magnitude, it has a similar bump part-way up its slope, though it also has fewer stars in its high magnitude clump at the end of the slope. This graph was considered "similar" to Figure 5.1.

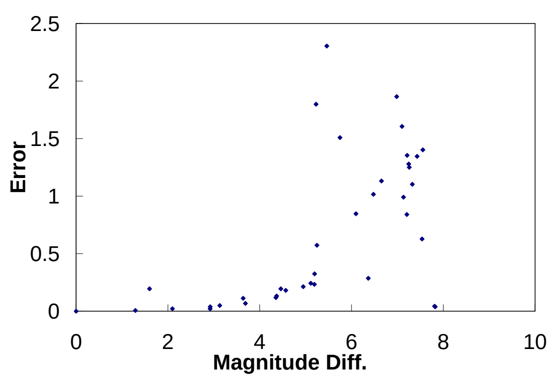


Figure 5.3: This error curve has a noticeably different shape from Figure 5.1. It has numerous flyer points both above and below the error curve, and does not have a distinct slope. This classed was classed as "not similar" to Figure 5.1.

Chapter 6

Results

6.1 Flats Matter

First, it showed, unsurprisingly, that those nights without flats in the proper filter had error curves that were considerably different than the error curve that used the flats from the same night as the data. The slopes, however, were not necessarily different. In the B filter, when no calibration images were applied, the graph had no magnitudes that differed from the brightest star by more than four, as shown in Figure 6.1. In Figure 6.2 the same graph is shown with only the zeros applied (left) and with both zeros and darks applied (right). Finally, in Figure 6.3 the same error curve is shown with the flat field also applied.

In Figure 6.4 the same results are shown for the R filter data of June 18. In the figure the left hand side is the error curve with no calibrations frames applied, while the right shows the curve generated with a complete set of calibration frames.

6.2 Time Does not Matter

A second analysis procedure showed that there was no discernible relationship between the time between the flats and the data, and the shape of the error curves. In my qualitative assessments of the shapes of the error curves, I could see no relationship at all between time elapsed and the error curve, and it was primarily to find any relationship between the time elapsed and the error curve that I decided to graph the log of the error vs the log of the magnitude difference. I took the slope of each log plot and made another graph, one for each filter, that plotted the slope of the log plot against the time, in days, between the data and the flat used to calibrate the data. These three plots, as shown in Figures 6.5, 6.6, 6.7, showed no discernible correlation between the time and the error curve, which backed up my

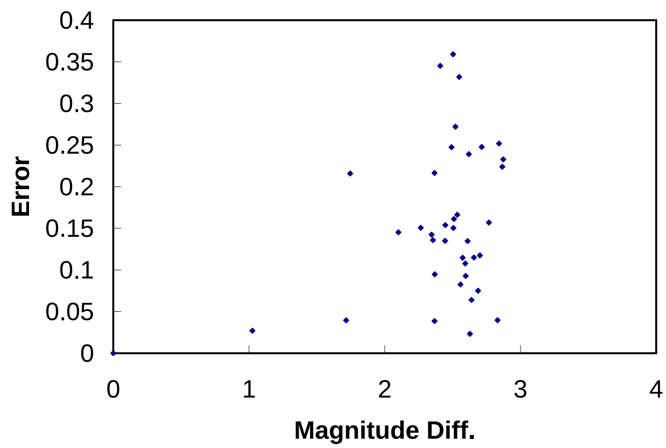


Figure 6.1: This is an error curve formed from a raw frame of the AN Lyn field, with no calibration frames applied. Data was taken in the B filter.

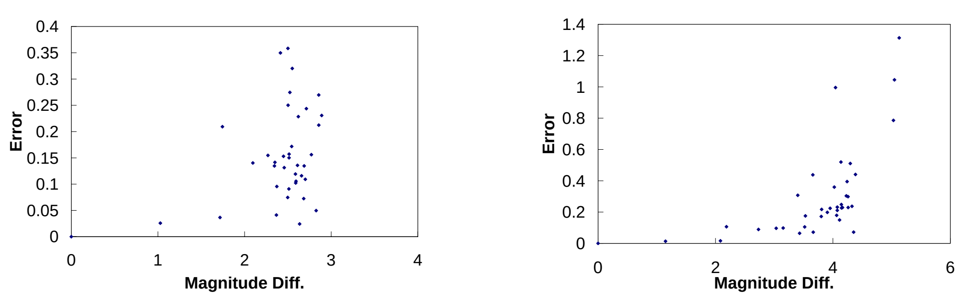


Figure 6.2: Same as Figure 6.1 only now with only zeros applied (left) and with both zeros and darks applied right. Data was taken in the B filter.

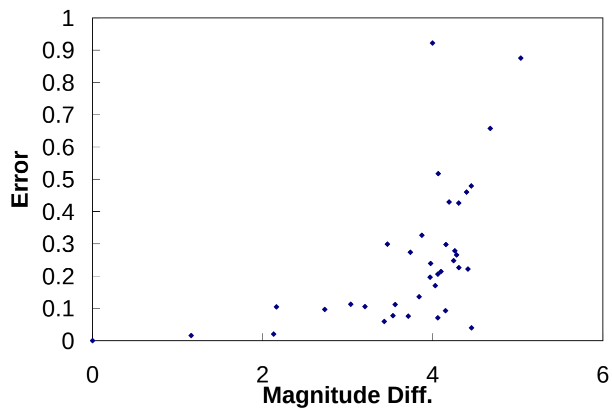
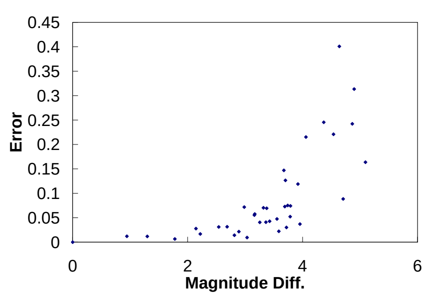


Figure 6.3: This is the fully calibrated error curve for the AN Lyn Field. Data was taken in the B filter.



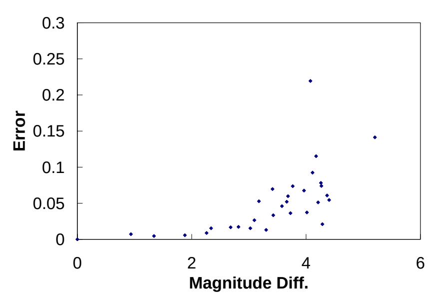


Figure 6.4: Same as previous figures, but in the R filter. The error curve for the raw frames is shown on the left and the fully calibrated data is shown on the right.

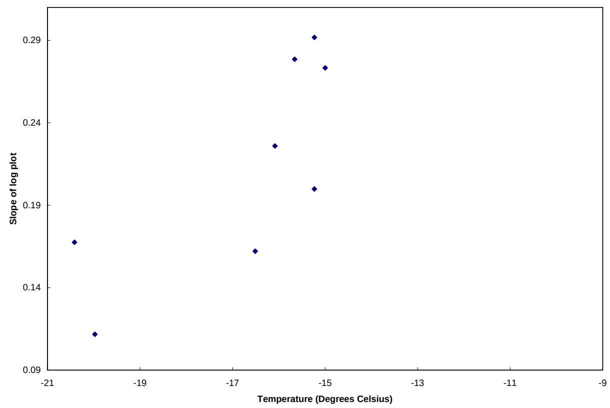


Figure 6.5: This plots the slopes of the log plots vs. the time elapsed between the flats and the data, just like every other single plot that involves time in this entire thesis. It uses data from the B filter.

initial qualitative assessment. Although some parts of the graph may show a pattern, it is not one that can be applied to all the nights. Excel could not find a trendline that came even reasonably close to fitting the data on the V or R filter plots even with a sixth order polynomial which would have been a ridiculously high order equation for so few data points.

6.3 Temperature Matters

Third, the only definite relationship I found was between the temperature of the calibration images when compared to the temperature of the original data and the error curve. The error curves in the V filter calibrated with calibration images that had temperatures similar to the temperatures of the calibration images from June 18 were visually very similar to the error curve from June 18. This relationship was much less obvious in the other filters, but the R filter error graphs had an unusually flat shape and low spread of magnitudes (see Figure 6.8) while the B filter had many

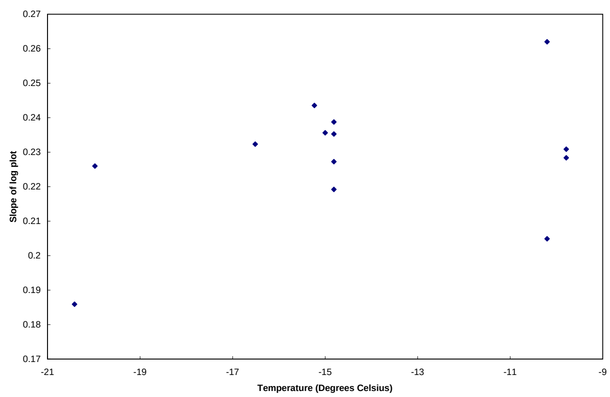


Figure 6.6: This plots the slopes of the log plots vs. the time elapsed between the flats and the data, using the V filter. Notice that there is no real continuity between the Figure 14 and this one, apart from the earliest flats producing a flyer point.

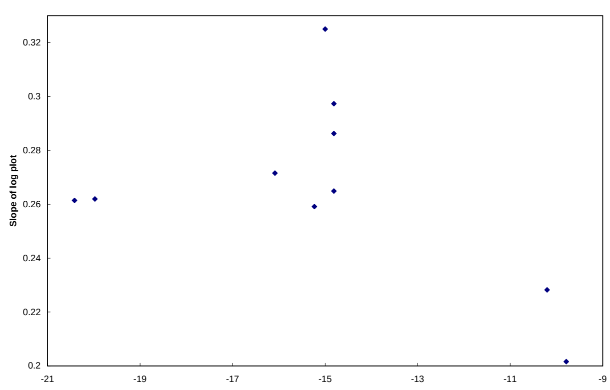
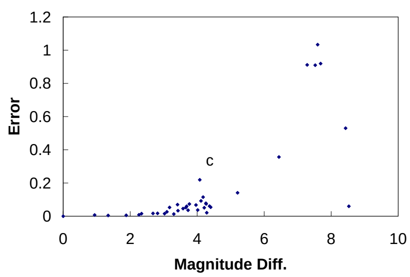


Figure 6.7: his plots the slopes of the log plots vs. the time elapsed between the flats and the data. It uses the R filter. Again, there is no discernible pattern relating to time, nor is there an obvious similarity between this fig and the previous two.

problems, even during photting, that made it difficult to build good error curves from. Thus, the B filter especially did not give reliable data, and I have never been sure how reliable the V filter's error curves were. Nonetheless, I plotted the slope of the log plot of the error curves versus the temperature of each of the calibration images in each of the filters. In the V filter, the results figures show a cluster of points at $-15°$ Celsius in the graphs for each of the calibration image types. No similar cluster is seen at $-10°$ and $-20°$ Celsius, but that could be because of the small number of points on these graphs. For the R filter, there are points that are close to each other, but considerably more spread than I would like, and in the B filter there are small clusters at $-15°$ Celsius. It is important to note that the data was originally taken at approximately $-15°$ Celsius. Thus, I conclude that for the best chance of getting accurate error curves, one must use calibration frames that have the same temperature as the original data. While having a different temperature does not guarantee a different error curve, it does make it more likely. This is most strongly seen in the V filter, and while I see no reason to think the B and R filters would cause a significant difference in the calibration images, their graphs are far less conclusive than the V filter graphs, and more work may be required in them to verify that temperature is important in them also. The B filter in particular gave me significant trouble, giving frequent error messages during photting due to low photon counts. As a further investigation of the importance of temperature, I collected all the calibration images from all the nights that had a temperature of $-15°$ Celsius and used all of them to reduce the data frames from the 18^{th} of June. When the resulting error curves were visually compared to the June 18, and when the slope of the log chart was found, it fit nicely into the center of the cluster of data points around $-15°$ Celsius, showing that flats, darks, and zeros at a unified temperature will produce an error curve similar to each other, regardless of when they were taken.



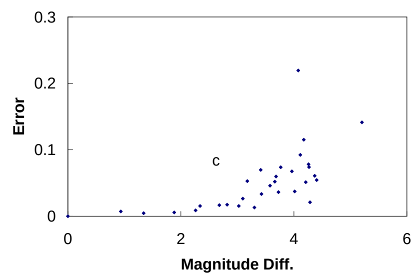


Figure 6.8: This is the error plot from the June 18 data in the R filter, using the June 18 flats. Notice that has a very small spread in magnitudes, since there are probably only six stars more than five magnitudes dimmer than the comparison star, and also note that it has no discernible break-off point or slope. All of the R filter error curves were like this, making them hard to analyze.

Chapter 7

Conclusions

7.1 Summary of Results

Although it is possible that the time elapsed between when a set of calibration images was taken and when the data was taken may matter, no such relationship was discernible from the data I took, in any of the three filters. My original purpose was to determine how much time affects the viability of flats, and that has been answered, at least to a degree consistent with an initial study. From my continuing analysis of the data, I found that it is very important that the temperature of the calibration images be the same as the temperature of the data, at least in the V filter, since no other temperatures gave reliable results in the V filter.

7.2 Possibilities for Further Research

I briefly looked at the number of flats used as a factor, but, surprisingly, found no obvious relationship between the error curves and the number of flats. It is quite likely that the temperature is important in all filters, but my graphs did not show clear clusters of data points at any temperature for the other filters, possibly due to low photon counts or other problems with the data. It has also been suggested that there may exist some "ideal" flat for any given temperature, and, if so, that an archive of all past flats, organized by temperature, could be incredibly valuable in reducing data. All of these are areas that may warrant further study by anyone wishing to study flats further.

7.3 Recomendations

I will simply end with the recommendation that flats, darks, zeros, and data all be taken at the same temperature to insure consistent results when reducing and deriving magnitudes from the data.