*CCD Astronomy*

# Honors Project

**In fulfillment of the Requirements for**

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By

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# Preface/Acknowledgments

This project has been many things during the course of working on. It has had its ups and downs from cloudy nights to the feeling that the telescope sometimes has had a mind of its own. However, I believe I have learned many things due to this research and have enjoyed it immensely. I would like to thank my partners Bineyam Kassahun and Jason York for all their assistance in this project.

I would also like to thank Dr. Peters and the Honor's College for all there assistants throughout my time at UNCP that has lead me here.

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# ABSTRACT

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Introduction/Abstract:

In this endeavor, I along with my partners Bin K and Jason York set about the goal of learning about and how to perform CCD Astronomy. We set about this task by learning how to operate several different telescopes and learn their particular operations of tracking objects, guiding, learning and correcting pointing errors. We learned about how to plan for when the best observations can be made for celestial objects. We were able to accomplish this by observing two to three times a week to compensate for any inclement whether that would interfere in observing. Our next goal we accomplished was to learned how to properly use CCD cameras and successfully interface these cameras to the Meade 16” Telescope. These cameras were the Santa Barbara CCD, Meade LPI, and the Meade Deep Sky Imager. Once we were able to interface these cameras to the Meade

Telescope, were learned how to capture images and learned modern astronomical data processing to get our final product images. These processes included how to properly combine, flat field and dark field captured images. Our final results were that we were able to get several well-processed color and monochrome photos of several celestial objects, including the moon, Jupiter, Saturn, and Orion's nebula. Our studies has also prepared us for continuing research in spectral analysis of star clusters that would allow us to determine ages of star clusters and individual stars.

## Telescope Operations

One of the main instruments that allowed us to take images of celestial objects was the Meade 16" LX200 Schmidt-Cassegrain Telescope. This was designed and has the ability to allow us and any other user to make detailed observations of the planets, nebulae, star clusters and other galaxies. This telescope is an advance mirror-lens design that's main use is for astronomical and terrestrial purposes. The Meade 16" is likely the most sophisticated and precisely manufactured telescope, optically and mechanically speaking, for the serious amateur (Manual, pg 5) and this allowed us to take images that most outside professional astronomers could not hope to obtain.

The telescope itself, without any necessary outside software, has a library that includes 15,928 Smithsonian Astrophysical Observatory objects, 7,840 New General Catalog objects, 5,386 IC (Index Catalog) objects 21,815 GCVS (General Catalog of Variable Stars, 110 M (Messier) objects, and 8 major planets; from Mercury to Pluto (Manual, pg 5).

These features are extremely useful, but are useless without properly aligning the telescope so that one can found the desired objects. In the way that we usually get a precise location for the telescope before we start our observations, besides the already programmed time and GPS position, is the two star alignment way. This process has the telescope start at a rough level and having the base level, which is not a problem since it is permanently floor mounted, and then we pick two stars greater than 90 degrees apart to align the telescope. We slew to those stars with the remote, and then confirm their position when they are each in the center of the cross hears of the view finder (Manual, pg 13). After we align the telescope, we usually use the Sky 6 software to talk to the telescope and the program moves the telescope to the object we want to view.

The typical way that celestial objects are located, is by a coordinate system not that much different then how locations on the earth are located, with the use of longitude and latitude lines. These lines are mapped on an imaginary sphere surrounding the Earth, where all stars look to be on known as the Celestial Sphere (Manual, pg 26). A representation of this sphere can be seen in Appendix A. Objects positions are identified by two sets of coordinates, Right Ascension and Declination. The Right Ascension coordinate is like the longitude coordinate on earth where it is measured as time on a 24 hour clock at 15 degree intervals and its beginning line passes through the Pegasus constellation. The Declination is correspondingly like latitude lines on the Celestial Sphere and center of 0° 0’ 0”runs through the constellations of Orion, Virgo and Aquarius (Manual, pg. 26).

Once a person has found the celestial object that they want to observe, then there are a number of techniques one has at their disposal in getting a clearly focused image. On trying to focus the telescope we used a Hoskins mask in order to focus on planets. This mask was simple to make by taking a piece of heavy cardboard and cutting three circles out of it in the form of an equilateral triangle. Then we would place the mask over the end of the telescope so that when one would look through the telescope, they would see the three circles. Once one could see the three circles, then one would adjust the focus until the three circles converged into one, indicating that the telescope was in focus.

The next item that had to be taken into account is the magnification of the object we were observing. In the magnification of an observed object is determined by two conditions, one being the focal length of the telescope, which for the Meade 16” is 4064mm, and the focal length of the eyepiece one is using during the observation. One calculates the magnification of the object by dividing the focal length of the telescope by the focal length of the eyepiece. To illustrate this, one could be looking at an object using a 7mm eyepiece, the same focal length as the Santa Barbara CCD, with the Meade’s 4064mm focal length and one would obtain around a 540x magnification (Manual, pg 24).

## CCD Background

To begin the process of understanding CCD photography, it would be helpful in understanding how a CCD operates. The common and simplest way CCDs are described in operating is called the "water bucket" idea. The analogy goes that buckets represent the pixels of a CCD array and raindrops from a rainstorm are the incoming photons. One would imagine a field of buckets in neat rows and columns covering the array. After it “has stopped raining”, in this case CCD integration, each of the buckets are moved in turn and measured to find out the amount of water that it had gathered. The record of the amount of water for each bucket, the final CCD image, will be a two-dimensional record of how much rain fell in the field (Howell, pg 8).

The make up of a CCD is basically pure silicon and is responsible for the detector to respond to the "various wavelengths of light". The absorption length is the distance in which 63%, one photon per electron, of the incoming photons will be absorbed by the silicon (Howell, pg 26). The light that is outside of the range around 3,500 Å to over 8000 Å, it will do one of three things: pass right through the silicon, get absorbed within the thin surface layers or gate structures, or it will reflect of the surface of the CCD (pg 27). When wavelengths get to be of the length of about 2,500 Å for thinned CCDs and 25 Å for thick CCDs the probability of detecting photons increase once again. Unfortunately, these photons cannot be used because the produce multiple electron hole pairs in the silicon and can damage the CCD (pg 28).

Since CCDs are limited in the wavelengths that they can optimally operate at due to the limitation of the silicon not being sensitive enough or the user wanting to enhance the performance of the CCD at specific wavelengths, CCDs have can be coated with different coatings to accomplish this task. The different coatings that can placed on the CCD allow it to be sensitive to photons that are normally too far in the blue side of the spectrum for the silicon to absorbed. These coatings are usually made up of "organic phosphors that down-convert incident UV light into longer wavelength photons" that the CCD can detect. The coatings are vacuum deposited and used often on front-sided illuminated, thick CCDs. This is a preferred method to inexpensively increase the blue response of the CCD without the additional cost and complexity of having to thin the device (Howell, pg. 21-22).

The gain of the CCD is set by its output electronics and determines how the charge that is collected in the pixels will be assigned to a digital number for each pixel in the output image. The gain values are given in terms by the number of electrons needed make one ADU step inside the A/D converter. They are listed as electrons/Analog-to-Digital Unit ($e^-$/ADU) and give value ranges from 1 photon counting to 150 or more (Howell, pg 39).

## CCD Operations

In taking CCD images, the steps at its face, seem simple enough. One takes four images of the intended object, each with a different filter. One takes a picture that filters out all the colors of red, then green, then blue and one picture with the clear filter that does not filter any of the incoming light out, known as the luminous picture. Once these pictures are taken, we used the CCDSoft software to first dark and flat field subtract each of the filtered pictures. Once this is done, we have to align each of the pictures so the objects in the frame line up with one another. When we aligned the images, then one is ready to adjust the ratio of red to green to blue to luminous to obtain a colored finished product. Using the DSI, LPI and SBIG CCDs, we were also able to take monochrome pictures of galaxies, nebulas and star clusters.

However, during the course of taking a CCD image there are many different problems that can and will arise. Fortunately these problems are understood and can be corrected.

The first problems that we or any other user has to deal with are problems that can occur inside the CCD itself. During the taking of an image a phenomenon of readout noise interferes in the process of getting a true picture of whatever object or object the user is taking. This readout noise or read noise for short hand is ordinarily defined for CCDs in terms of how many electrons are introduced per pixel into the final signal is readout. This readout noise is made up of two components that are inseparable; first, the conversion of the analog signal to the digital number because that is not perfectly repeatable (Howell, pg 30). This is due to the fact that the on-chip amplifier and the A/D circuit produce a statistical distribution of the possible answers around the mean value (pg 31). The second component is that the electronics of CCDs will insert random electrons into the process, which will produce undesired random fluctuations in the final outcome. When combined, these two components create an additive uncertainty for the pixels' final output value. The read noise is the average level of that uncertainty and the limited factor on the level is the properties of the on-chip output amplifier and the output electronics (pg 31).

The other factor one must take into account that may cause additional interference with picture taking is the problem of dark current. This is due to the fact that all materials that has temperatures much greater then that of absolute zero are subject to internal thermal "noise". Since this condition will apply to the silicon inside a CCD and when the temperature is high enough, the valence electrons will become free. Once these electrons are free from their bonds, they will be collected in the potential wells of the pixels with the other electrons. So when the read out is produced, these "dark current electrons" will be part of the incoming signal and be indiscernible from the true astronomical photons. Since the thermal production of electrons from the silicon is a function of the temperature of the CCD itself, it is usual practice to have some form of cooling when using the CCD for astronomical purposes (Howell, pg 32). The Dark Current of CCDs is usually defined as either "the number of thermal electrons generated per second per pixel or as the actual current generated per area of the device" with measurements of Pico amps per squared centimeter (pg 32).

In correcting these problems, the user must take a number of steps. The first step is the taking of a bias image. The purpose of taking bias or zero images is to let the user measure the noise level at zero of a CCD. When an unexposed pixel, who's collected photoelectrons would be zero when it is readout and A/D converted to a mean value that will have a small distribution around zero (Howell, pg 37). To prevent negative numbers from being in the output image, the electronics in the CCD are set to give a positive offset value for the accumulated image. This offset value is the mean zero level is the bias level. A normal bias lever may be a value of 400 ADU per pixel of a gain of 10 e-/ADU would equal 4,000 electrons. At first glance this might be a large number of electrons to use, but in practice the temporal drifts that occur in the electronics in the CCD due to the "due to age, temperature, or poor stability in the electronics, as well as much higher read noise values" warrant the use of these levels (pg 38).

In the reduction and calibration of a CCD image, one uses a basic set of images. These set of basic images are three calibration frames of bias, dark and flat field and the data frame of the object or objects one is calibrating. These images are basically the same, even if they are generated by different ways, in imaging, photometric, and spectroscopic applications. To correct the object frame, one would first subtract a mean bias frame or a dark frame if it would be required. Next, one would divide the resulted by the mean flat field image, that itself has been bias subtracted. When these two steps have been completed, the object frame will be corrected for bias level, dark current and the nonuniformity within each of image pixels (Howell, pg 58). In other words, the Final Reduced Object Frame will equal the Raw Object Frame minus the Bias Frame divided by the Flat field Frame (pg 60). In taking dark field images with our CCD, we found that in our pictures that there would be a lined down the left side of the frame, which suggests that there is a column defect in the manufacturing of the CCD. When we process the images that we take, the CCDSoft software that we use to process the images take the Bias Frame into account when we Dark Field subtract each of our color filtered images.

Other problems that must be corrected in getting desired pictures are the need for flat fields and their use. Due to physical limitation in the construction of CCDs, pixels within CCDs are not identical to one another. The pixels that are within a CCD each have a minor different gain or QE value in relation to its neighboring pixels. To correct this problem, it is necessary to flatten these relative responses of each pixel to the radiation that is absorbing. This is accomplished with a flat field image, which is ideally, an image that "consist of uniform illumination of" each pixel "by a light source that has an identical spectral response" to the images taken. This should result in a flat that is "spectrally and spatially flat" (Howell, pg 48). When one obtains the flat field image, then on divides each of the object frames by it and this causes the removal of the pixel-to-pixel variations (pg 48). The two common types of flat fields that are taken are ones called dome flats and sky flats. Dome flats are flats taken inside the illuminated dome of the observatory and sky flats are ones that are taken of the horizon at dusk or dawn or “obtaining spatially offset images of the dark night sky” (pg 49). When we would take flat fields for our observations, Jason and I preferred to take dome flats instead of sky flats. The dome flats would give us a uniform illumination for the frame that we could later use for subtracting out bad pixels in the photos that were going to be taken that night (Howell, pg 49).

The other problem that we ran into was that when we would attach any of the cameras to the telescope, we found that one could not focus the object. This was because of the addition of the camera and color wheel, it changes the focal length of the telescope. To correct this we would use the focus reducer that would properly focus the image into the CCD.

Several other minor problems that faced us in taking quality pictures are that when trains pass by the observatory and trial and error of exposure times for taking images. The passing of the trains would noticeably vibrate the telescope during observations. Exposure times were important because if the times were either too long or short, the image would be too dim or would blight out the image.

Finally through all this hard work are final results were a number of monochrome and colored images. The images we were able to obtain were that of the several planets that included Saturn (Appendix D) and Jupiter (Appendix E) and the Orion Nebulae (Appendix B and Appendix F).

In conclusion, the process of taking photographs of objects in the night sky is far more difficult then one would first think. It is an endeavor one must commit to if one is doing it for research or as a hobby. In our commitment, we observed two to three times a week or more. Many problems can and did arise for our research group. One of the obvious problems that any astronomer faces is the weather conditions. For the most part, we were able to deal with this problem by observing the two to three times a week and sometimes more. Once we overcome these problems when observing, we went on to properly combine and created finished images. The results were a number of images including Orion's nebula, the moon, Saturn, and Jupiter. In future, from the skills that we have acquired, we could do spectral analysis on stars clusters to determine their ages and that of individual stars.

## References Cited

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Rowlett, Russ. " How Many? A Dictionary of Units of Measurement." 2001. University of North Carolina at Chapel Hill. 5 April 2006 <http://www.unc.edu/~rowlett/units/index.html>.

Meade Instruments Corporation. Instruction Manual: 16" LX200 Schmidt-Cassegrain Telescope.

# Appendix A

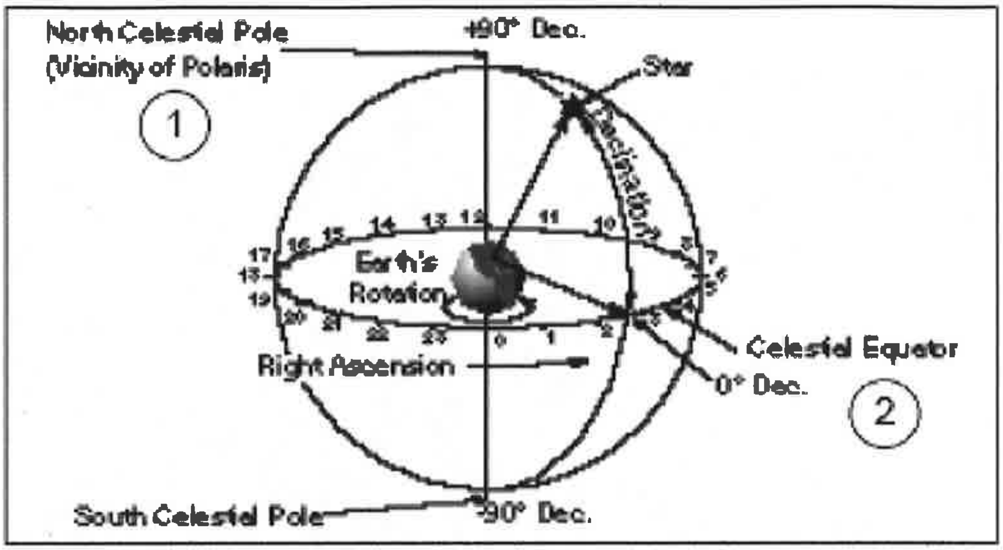


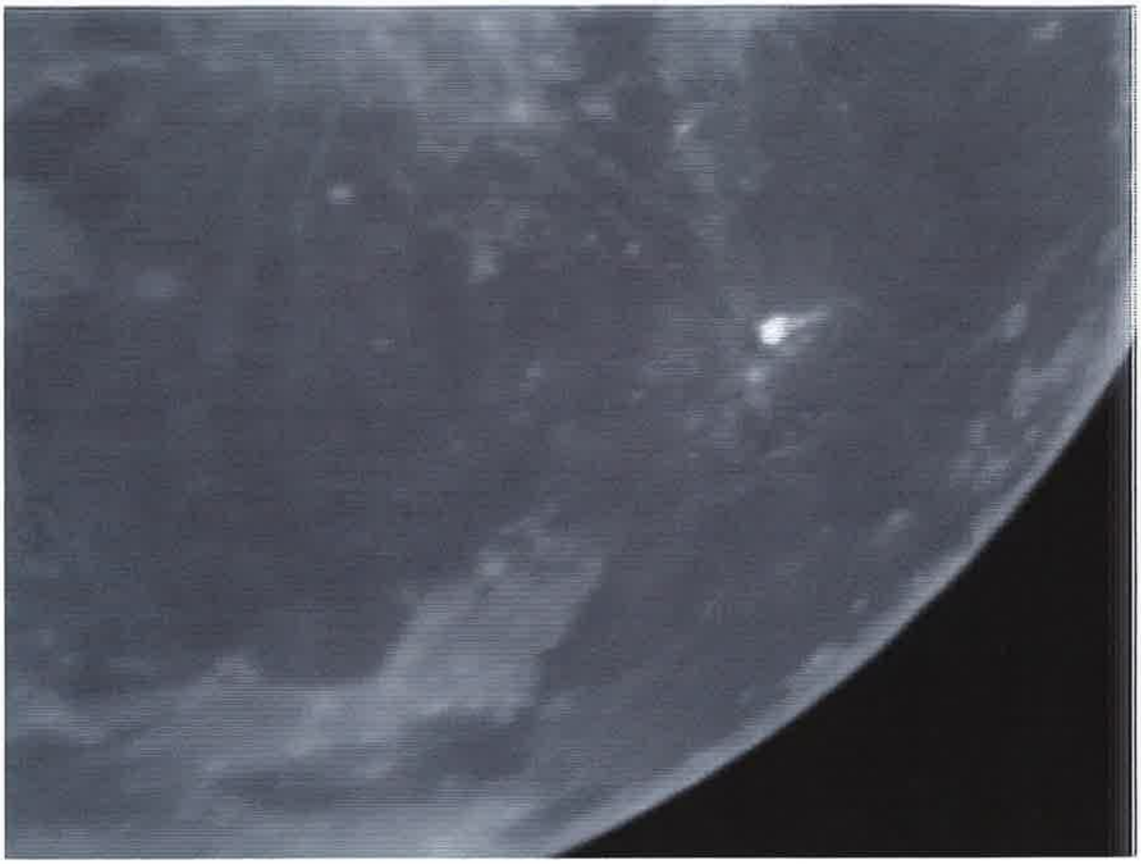
Fig. 9: The Celestial Sphere.

# Appendix B

Orion's Nebula

# Appendix C

## The Moon



# Appendix D

Saturn

# Appendix E

Jupiter

# Appendix F

Orion's Nebula

Table 1

| | |
|---|---|
| Å | A metric unit of length, equal to 0.1 nanometer or $10^{10}$ meter (Rowlett). |