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PHYS 498W

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Astrophotography

Astrophotography is a specialized type of photography that involves recording images of astronomical objects and large areas of the night sky. Anything in the sky can be used for astrophotography including stars, planets, galaxies, comets, and even the International Space Station. Long exposures can be used for tracking an object across the sky, while shorter exposures will allow for a crisper image of that object. This can be done with a video recording or with several individual images that are taken in sequence. The images cannot be taken too far apart, or the final result will not be of high-quality. These images and video frames can then be stacked and manipulated using a photo/media manipulation software application like Photoshop, but there are a variety of different tools that can be used.

The main objective of the astrophotography portion of the project is to learn how to capture real-time data, process it, and manipulate it to achieve a final result. Learning to capture real-time data, employing basic observing skills, working with image/media processing applications or tools, and performing library searches were all essential components of this project. The final result is creation an aesthetically pleasing image. Of course, that is easier said than done and usually requires many years of professional experience and practice to learn how to create the perfect image time after time. The images for my project were all taken using a filter wheel containing 10 different filters, 3 of them being color filters and 4 infrared filters. Since there are so many different filters, and not yet possessing years of professional experience, a final pleasing result was not obtained; this will be explained later in the paper. See Figure 1 for some sample images from more experienced astrophotographers.

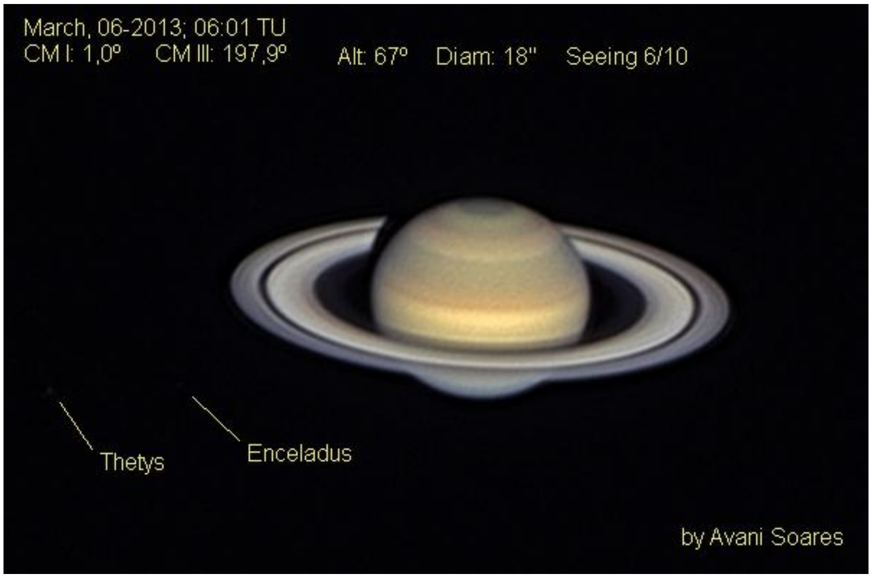


Figure 1: Here are images of Saturn and Jupiter after all of the necessary processing that are professionally done. The first image of Saturn was done by Avani Soares and the second image of Jupiter was done by Sean Walker of Sky and Telescope Magazine.

The physics behind astrophotography is fairly simple. Photography is the capture of light reflecting off of an object onto a reactive medium. As such it is a momentary representation of the object in front of the lens the light passes through. The longer the lens is held open, known as the exposure, the more photons are captured. Due to the Earth's rotation as it spins around the "celestial pole", depending upon their location in the night sky, stars can appear to move across the sky. By using astrophotography techniques to photograph them we can measure both their speed and their paths. While not the closest star, due to its geosynchronous location, Polaris (also known as The North Star) is a "stationary" star. As a result, Polaris is good for calibrating instruments as well as locating other objects in the sky as it is a good landmark in the sky. As for planets, we already know their orbits so tracking them is more easily done. Since moving or holding, a telescope or camera with the hands will cause blurry images due to normal respiration and/or shaking of hands or body, several different tripod tracking mounts have been developed for use by both amateur and professional astrophotographers. When capturing data on planets, their spin rates must be taken into account. This is the reason why photos must be taken quickly, generally using large aperture settings at very high shutter speeds. Finally, you must also remember to take planetary rotation into account as well, as each photo will be slightly different. Failure to take this into account will result in blurriness that cannot be corrected when stacking images, and could lead to loss of valuable data as images are discarded.

The enabling technology that was used for this research was from The Naval Research Laboratory's Midway Research Center in Stafford, Virginia. Their Brashear 1-meter Telescope was used for all observing. It has blind pointing accuracy exceeding 7 micro radians while traveling at 25 degrees per second and precision exceeding 10 Nano radians. This device also has active tracking based on any target that is selected via the library. The camera that was used for all data capture was a SBIG ST9 XE CCD Camera. This camera has an image field that is 512x512 pixels, 25 micro pixel size, and integrated CCD capabilities. The filter wheel is an integral part of the SBIG camera, boasting 10 filter slots. Before any data is captured, each filter's optimum focus must be found. This is accomplished by taking numerous different images with each filter on different focus settings and comparing them to achieve the best possible image setting. With regard to the filters, there are two open filters and one dark filter. The open filters are simply clear lenses that don't filter or restrict any light, while the dark filter doesn't allow any light to pass through. The dark filter is used for gathering "flats", which are images that when combined with the others help to reduce noise. The filter information is found in Table 1 and Table 2.

Color	**Wavelength**
Violet	400-450nm
Blue	450-490nm
Green	490-560nm
Yellow	560-590nm
Orange	590-635nm
Red	635-700nm

Table 1: This table contains the visible light spectrum in wavelengths. This is used to compare color wavelength to filter wavelength.

Filter	**Best focus**
F1-415nm	830 µ
F2-500nm	1050 µ
F3-Open	N/A
F4-670nm	1100 µ
F5-870nm	880 µ

F6-Open	N/A
F7-940nm	870 µ
F8-1010nm	1080 µ
F9-1020nm	1080 µ
F10-Dark	N/A

Table 2: The tables above contain the wavelengths of light, the filer names and their associated wavelengths, as well as their focuses.

The process of astrophotography appears simple, but in reality it is much more difficult than it sounds. First, data must be captured. For this a telescope and camera are the only required materials, but a tracking mount is highly recommended. Also, in general any camera will suffice, even a phone camera. Some bare images can be found in Figure 2, which have no processing or stacking done to them yet.

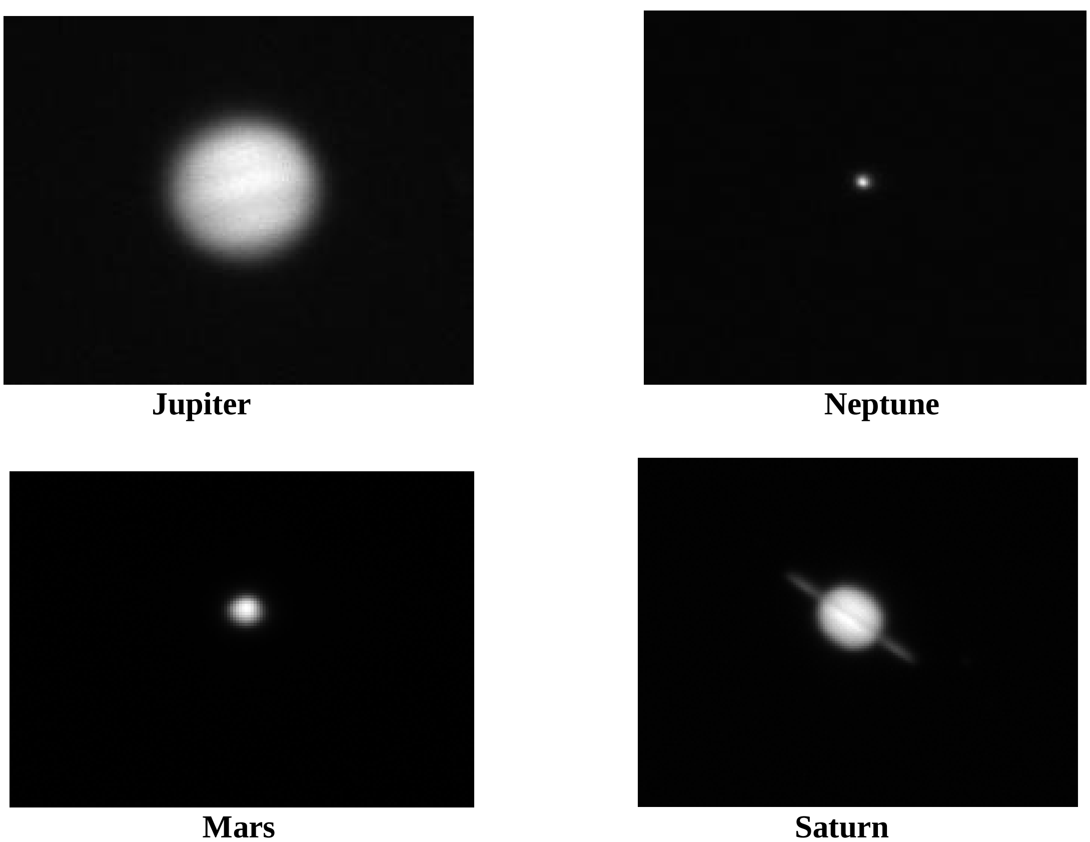


Figure 2: Some bare images are located above, they contain no post processing or stacking.

Next, the images need to be “stacked”. Stacking is the process of combining many short exposures of an object into one image. The purpose of this is to improve the SNR (Signal-to-Noise Ratio) of the images. The software will average the brightness at each pixel as it combines multiple images to make a single image. See Figure 3 for an example of a stacked image.

Figure 3: Above is an example of a stacked image. This image is composed of 10 separate images from filter 7.

Since this data is taken with a filter wheel, each filter has its own exposure length depending on the planet. When looking at Table 3, which shows the exposure lengths for each planet listed, you will notice that F10-Dark is missing. The reason for this is because it is a dark filter, allowing no light, so the data captured by it will all look the same. The images captured using filter 10 must be taken at all exposure lengths to correspond with the other filters when stacking. In addition, since some planets are brighter than others, exposure times must be adjusted to compensate, resulting in smaller or larger exposure times. (See Table 3 for the exposure lengths for each planet.) As can be seen by looking at the table, the exposure lengths on Neptune are much longer than any of the other planets because it is significantly farther away. It is also smaller than both Jupiter and Neptune.

Filter	Exposure Length on Jupiter	Exposure Length on Neptune	Exposure Length on Saturn	Exposure Length on Mars
F1-415nm	0.001 seconds	4 seconds	1 second	1 seconds
F2-500nm	0.001 seconds	4 seconds	1 second	1 seconds
F3-Open	N/A	N/A	N/A	N/A
F4-670nm	0.001 seconds	0.9 seconds	1 second	1 seconds
F5-870nm	0.001 seconds	20 seconds	5 second	0.1 seconds
F6-Open	N/A	N/A	N/A	N/A
F7-940nm	0.001 seconds	10 seconds	2 second	0.1 seconds
F8-1010nm	0.001 seconds	0.4 seconds	1 second	1 seconds
F9-1020nm	0.001 seconds	0.001 seconds	1 second	0.1 seconds

Table 3: Filter exposure lengths per filter on each planet are found above.

Some images in the data will be filled with noise or over saturated and are easier just to exclude. Further, some images may be so far off because of wobbling that you are just better off leaving them as well. If these images are left in, it will cause blurriness in the final stacked image. Remember the goal is to have the clearest, most pleasing image possible. See Figure 4 for an example of an over saturated image. A solution to over saturation is to lower the exposure time, which in turn will reduce the amount of photons that come into the camera lens. The solution that the Naval Research Lab uses if the image is still too bright, is to close the dome as far as needed, even as small as only 1 inch wide. This will significantly reduce the amount of light into the telescope and camera.

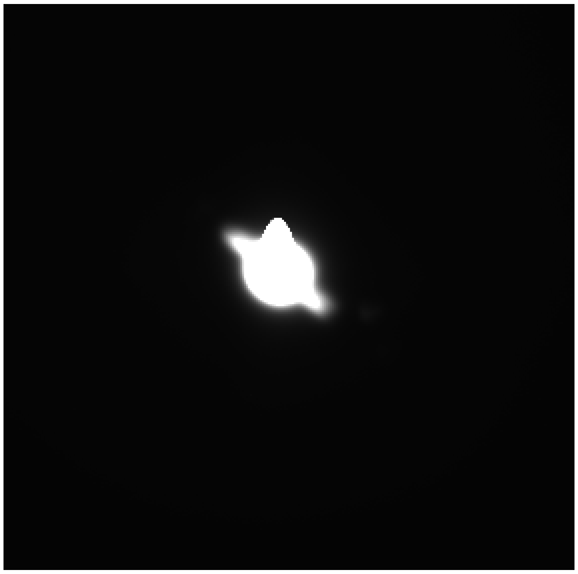
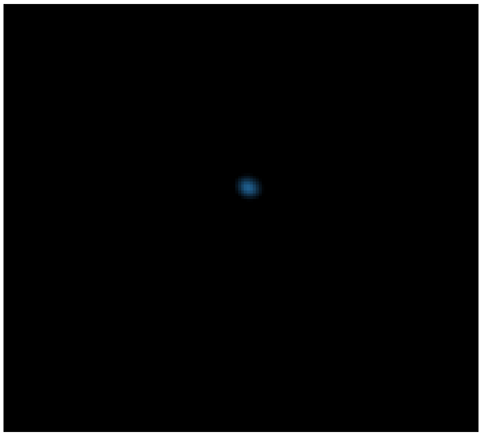


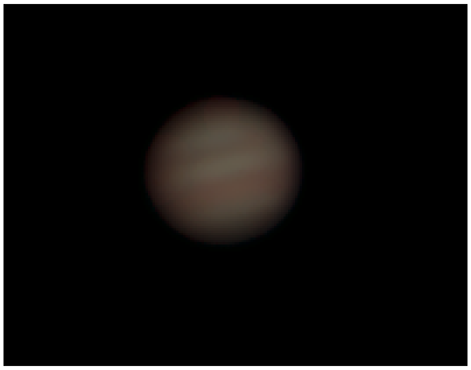
Figure 4: Above is an example of an oversaturated image. This is caused by too much light being absorbed by the camera.

The final step to be done is post image processing. This is done by roughing out the images to create a single, aesthetically pleasing, final image. The post image processing can be as easy as simply changing the image's brightness, or it could be as complex as creating algorithms to remove noise and light gradients. The final images can be found in Figure 5.

Mars



Neptune



Jupiter

Saturn

Figure 5: The final processed images are found above.

As could be expected, without years of professional experience, a few problems were encountered while capturing the data and doing the image processing. The first problem encountered is an astronomer’s worst nightmare: weather. Due to rain or just cloudiness, numerous scheduled observing times had to be cancelled. Aside from rain, the atmosphere can also cause a lot of problems. Atmospheric humidity can be a huge factor when observing. On a humid night, the sky can appear blurry and hazy, resulting in poor data collection. It is much easier to observe in the winter than in the summer, as the sky is much clearer and the atmosphere is more stable.

The next problem encountered was that dark images were being produced after stacking. The original thought was the software settings were not correct and needed tweaking. RGB files stands for red green blue and JPG is the standard image saving format. So after going through and changing some of the settings, first changing the file formats from .fits to .rgb files and then to .jpg files, the problem persisted. In fact, the problem was never completely solved, but it was accepted, as the filters were not only red, green, and blue. The filters were essentially 7 different colors and the software could not complete an image with full aesthetically pleasing color. Instead the software adds the color but it is very subtle.

The final main problem encountered was the Neptune data itself as the data captured by five of the seven filters was totally unusable this is because all of the images in those data sets were either filled with noise or that Neptune couldn't even be seen. This could have been caused by the fact that Neptune is mainly only a blue planet, and therefore didn't have a use for the data from the other filters. In the future the data will be looked at right after capture, so it can be determined right away if it is clear, or if another data set is needed to be taken. Figure 6 shows an example of what the Neptune data looked like and why it was so poor.

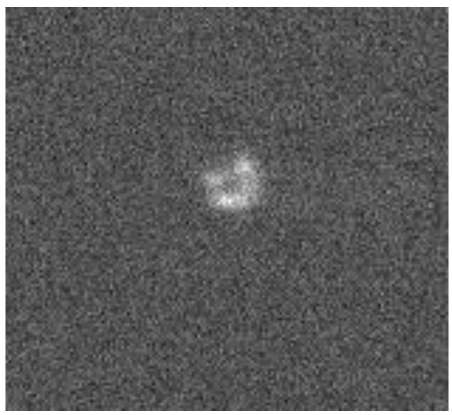


Figure 6: The image above is one image from the Neptune data set. It is easy to tell that this data is unusable.

In addition there are a few other things that if changed, would aide in a better end result. Other than using different filters, capturing data as a video rather than as a single image is one thing that will be done during the summer. A video file will allow hundreds of frames that can be pulled out rather than only the ten to twenty single images from the camera. This allows for better quality images as there are more to choose from. Another thing that would be changed is writing down and taking better notes in a laboratory journal as the experiment proceeds. While trying to analyze the data captured for this experiment, there were numerous times when it would have made things a lot easier if there had been better notes. These two changes are fairly simple but should have a very large impact for the next try.

In summary, the original goal of this project was to capture another data set with brand new filters to get a better color image, as well as determining the amount of water vapor in the atmosphere. With another data set using other filters, comparisons could be done between the two sets of filters, such as analysis of ratios and image quality. Due to time restraints and availability of the telescope these goals were not accomplished. This will take place in the summer on a clear observing night and analysis will be done shortly thereafter.

Another goal was to estimate the black-body temperature of an astronomical object. Black-body radiation is the type of electromagnetic radiation within or surrounding a body in thermodynamic equilibrium. Planets and stars are not in equilibrium, but the technique can be used as a good approximation. The majority of energy radiated is infra-red, so we will use the filters ranging from roughly 700nm to 1000nm. The data taken for this would be used to try and make an instrument to use at night using stars since a daytime version was already in use. The observing strategy for capturing this type of taking data involves a few different steps. First in order to estimate the black body (color) for each of the targets, we need plenty of SNR (signal-to-noise ratio). On each target we do not want to dynamically focus as well as never saturating the images. Next, darks will be taken to match each of the unique exposures. Exposures on Polaris ranged from .5 seconds to .1 seconds and exposures on another star, Vega, ranged from .1 seconds to .8 seconds. These measurements would be repeated as many times as possible during the summer and fall. Approximately ten days worth of data was taken during the summer, and about five days worth was taken during the fall. Unfortunately due to unforeseen circumstances, the data was not able to be analyzed. The plan is to analyze the data in the summer with some of the other employees at the lab.

Overall, even though not all of the goals were met, the project can be considered a success. The final images may not have been the best pictures available but they were considered good for an amateur astrophotographer with very little experience. Many things were learned and next time the images should be even better.