

ASTR 469 Final Project, Astro Photography

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ABSTRACT

This project had the goal of observing the Orion Nebula using the White Hall Telescope and calibrating the image in order to produce a high quality detection. The detection was made, then calibrated to reduce noise and create a clear picture. The noise factors were discussed, and a comparison between wavelengths was made which showed that the visible range which was observed is highly efficient at detecting gas from the nebula.

Keywords: astronomical data – magnitudes – stars

1. INTRODUCTION

Optical Astronomy refers to the branch of astronomy which is visible to the human eye. This corresponds to wavelengths of 400-700 nm and optical telescopes are typically used to observe objects in this range of wavelengths. Observational astronomy was first started in 14th century when Galileo Galilei started using a self crafted telescope to study objects in the night sky such as the planets in our solar system. Much progress has been made since then, with optical telescopes being capable of observing far away galaxies, stars, and even detecting oxygen in exoplanet atmospheres (Ben-Jaffel & Ballester 2013).

For this project we use a Celestron 14" telescope, which we will discuss in further detail in section 2, however, some notable optical telescopes which are larger and more sophisticated telescopes but work using the same principles include the Keck Observatory (Berriman et al. 2014), the South African Large Telescope (Whitelock & Oluseyi 2008), and even space based telescopes such as the Hubble Space Telescope (Meylan et al. 2004).

The Orion Nebula, at a distance of 1344 light years away (Reid et al. 2009), is one of the brightest nebulae visible with it even being visible to the naked eye in a sky relatively unaffected by light pollution. The Orion Nebula has an apparent magnitude of 4, and a diameter of approximately 66 arc-minutes (Frommert 2009). It is catalogued as Messier 42 or NGC 1976 and is located in the sword part of the Orion constellation. A nebula such as this is where stars are currently starting to form. There is an immense amount of gas surrounding the area, which one can see in figure 1, and this gas is mainly composed of hydrogen, which will eventually start to grow closer and closer together and eventually

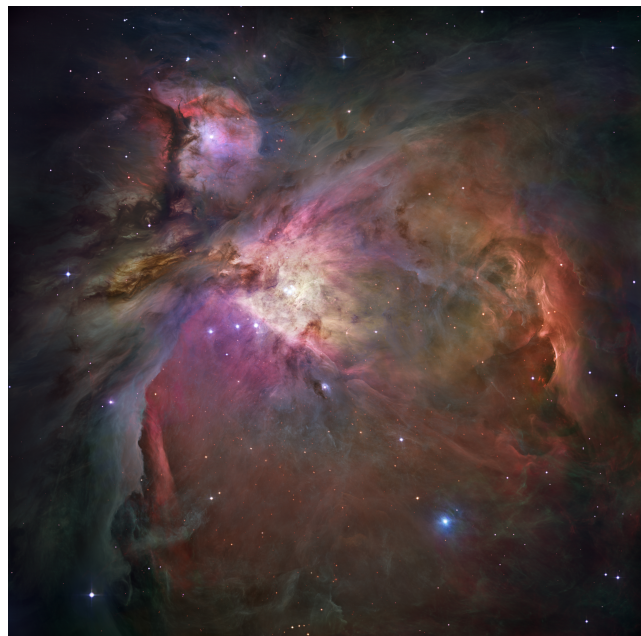


Figure 1. Credit: NASA/STScI/ESA

gain enough mass to form new stars. As it is such a bright object, it is no stranger to astrophotography and provides beginners such as undergraduate students as ourselves, a good starting point on how to find and capture objects in the night sky.

1.1. Hypothesis

This object was chosen mostly due to its brightness and visible time. It was ideal to choose an object which was going to be visible early in the night and would remain visible for a few hours, giving the observers enough time to capture it before the object set for the night. For this project, we hypothesise that the Orion Nebula will

be bright enough to be visible through the White Hall Observatory Telescope, and that the CCD will be able to capture most of the gas surrounding the object as to create a well defined plot with the different intensities between the stars and different gas components. The Orion Nebula will also be up at the beginning of the night, and although it will set relatively early, there will still be more than enough time to capture the image and acquire enough data.

2. METHODS

2.1. Observations

The telescope used to observe is a Celestron 14" Edge HD OTA. This model of telescope has a 356 mm aperture, f/11 focal ratio, 3916mm focal length and Star-Bright XLT optical coatings. It was designed intentionally for astrophotography and is ideal in capturing wide-field deep-space objects. The design of the telescope makes sure the images are coma free and visibly sharp stars. A 2-inch, 23 mm Luminos eyepiece is mounted on the telescope to help with alignment.

The data was collected with a CCD camera designed by *Diffraction Astronomy and Scientific Imaging Solutions*. This CCD is a 8.3 megapixel CCD with 5.4 micron pixels. It is capable of adaptive optics and has a self guided filter wheel option. The device can then be connected to a computer through it's USB 2.0 or Ethernet connection where it communicates to the CCDOps software and uploads the data for processing. CCDOps is the software used to take the data and is a free program that operates cameras such as the CCD used in this project. There are many options to select when taking an image with this software, for this project, it was important to set the cooling to -20°Celsius in order to minimize noise. Another option was to select the exposure time. Many times were tested such as 7s, 10s, 20s, and 30s, and it was determined that for this project, the 20 second exposure time was producing the best image.

The data were taken on April 26th 2021 at the White Hall Observatory in Morgantown, West Virginia at a local sidereal time of 10h31m12s. The object was relatively low on the horizon as it had a hour angle of 04h56m25s. The sky position and set time of the Orion Nebula at this time of the year was a potential risk to capturing the object since it was only going to be visible for such a short period of time. However, by capturing the object as soon as the sun set and as soon as it was visible, this increased the chances at getting an image. Another risk was that if it took longer than expected to set the camera up, it would be possible that the object sets before being captured, but since there were no problems and everything was able to be set up before

sunset, we were able to focus the camera as soon as the object was visible and capture clear data of the Orion Nebula.

Due to the object being so low over the horizon, the airmass at the time of observation was relatively high at 9.31 airmasses. This means that this object was not as bright as it could be when it is higher in the sky and at a lower airmass, since objects like these follow the relationship according to,

$$X = \sec(z). \quad (1)$$

Or more accurately, to account for the spherical nature of the earth, we would use,

$$X = \sec(z)[1 - 0.0012(\sec^2(z) - 1)] \quad (2)$$

Because the Orion Nebula is so low on the horizon, our value for z is very high, resulting in a large number for airmass.

It is possible to convert the Equatorial Coordinates of right ascension and declination to Local (Horizon) Coordinates using the equations,

$$\sin Az = -\frac{\sin HA \cos \delta}{\cos El} \quad (3)$$

$$\sin El = \sin \delta \sin \phi + \cos \delta \cos \phi \cos HA, \quad (4)$$

The right ascension of the Orion Nebula is of 05h35m17.3s and its declination is of -05°23'28" and therefore we can easily find that our object has an altitude of +05°40'48.3" and an azimuth of +254°14'54.8"

Considering that the Orion Nebula is already in a period where it is setting so early, the observation LST of 10h31m12s was most likely the ideal time to observe. Any time earlier than that and the sun would still be out, causing the object not to appear as bright and any time later would cause the object to disappear over the horizon and no longer be visible. Typically however, a better observation would have been taken earlier in the year, when Orion was higher up in the sky and there was not as high of an airmass affecting the visibility of the object.

2.2. Data

Many steps were taken in order to calibrate the image and reduce noise. As discussed in the previous section, the camera was configured to operate at -20°Celsius. This reduced the "dark current" which is a source of noise represented by,

$$\sigma_{Dark} = n_{pix} \times dk \times t \quad (5)$$

where dk is the rate for number of electrons per pixel per second.

After the observation was taken, it was also important to calibrate the image. This was done by taking a bias frame, a flat field, and a dark frame and then combining it with the image. The bias frame is an exposure as short as possible while the cap is still on the telescope. The point of doing this is to capture no light and measure the read noise of the CCD. The flat field is a uniformly illuminated image inside the telescope dome to detect variations in the brightness of the image due to imperfections in the optics and CCD. The dark frame is an image which was taken with the same exposure time as the actual observation (20 seconds), with the telescope capped. This gives a way to look at the response of the optical system and will show bright pixels which are due to electronics rather than actual image data. All of these frames were taken after the observation, which was especially good for the dark frame as we already knew the exposure time of the actual image. We then combined these frames in python arrays by using the equation, $\text{calibrated_image} = ((\text{light} - \text{bias}) - (\text{dark} - \text{bias})) / (\text{flat} - \text{bias})$. Which then gave us an image where the noise is removed and we had a calibrated observation ready for analysis.

Once entered into python, it was then important to find the appropriate minimum and maximum magnitude for the image. To do this, we want to set $V_{\min}$ at a point in where it is past the noise. We plot a histogram which clearly show the noise, such as figure 2 and set $V_{\min}$ as a value just past the peak in noise. For this image, the value of 0.147 was chosen. The value for $V_{\max}$ is somewhat harder to justify, seeing that it deals with noise levels which are somewhat harder to identify in a graph such as figure 2, but after many trials, it was determined that a value of 0.19 yielded optimal results.

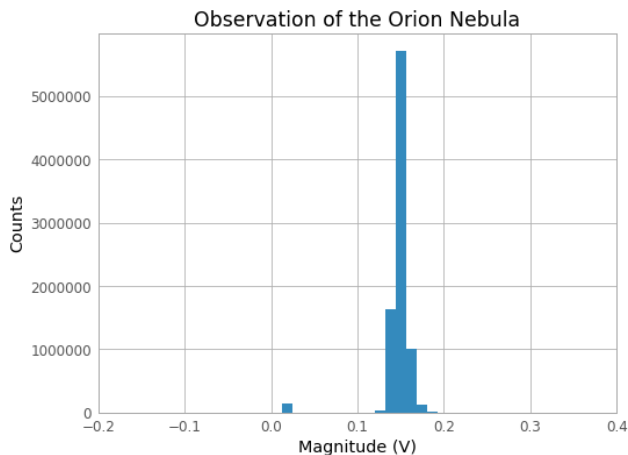


Figure 2. Histogram of the CCD image plotting the counts versus magnitude. This histogram clearly shows where the noise lies in the values of magnitude.

The data were then plotted on coordinates axes as a function of intensity. This creates a spatial representation of what the CCD detected and clearly displays the object in a way we can understand. In order to better visualize the intensity, a color map and color bar was added to the data. This is very helpful as it will separate the data into things which are of the same magnitude, making it easy to identify stars and separate gas clouds.

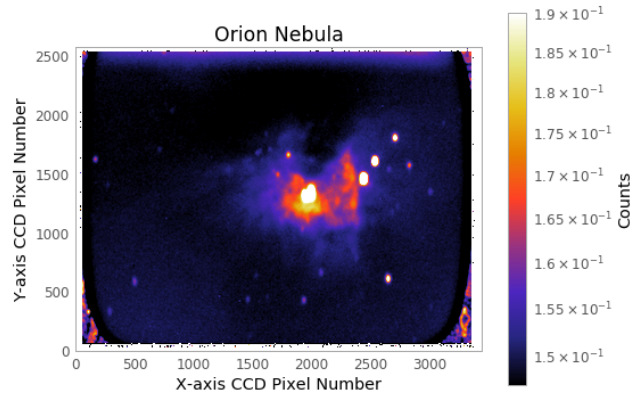


Figure 3. Calibrated CCD image of the Orion Nebula taken with the White Hall Telescope.

3. RESULTS

The resulting image, shown in figure 3, clearly shows the Orion Nebula as well as the stars in its proximity. It is mapped with the warmer colors being higher intensity and the cooler colors being a lower intensity.

4. DISCUSSION

4.1. Image Noise

One of the most noticeable aspects of the image in figure 3 are the bottom corners and top of the screen which clearly show sources of error or noise in the data. All these features are most likely caused by the calibration process. Since the corners of the telescope are likely to not be as bright as the center, it is possible that there is a calibration from the flat field image which is affecting that part of the calibration process, and causing some pixels to be over-corrected. It is possible that something similar is happening at the top of the lens. It also is possible that some light could have entered the telescope if it was not capped uniformly, causing light to seep in which would only be detectable by the 20 second exposure of the dark image.

An important aspect which was included in the methodology was that the minimum magnitude, $V_{\min}$, was chosen to be 0.148 and therefore the image contains only any noise and data which has a magnitude above

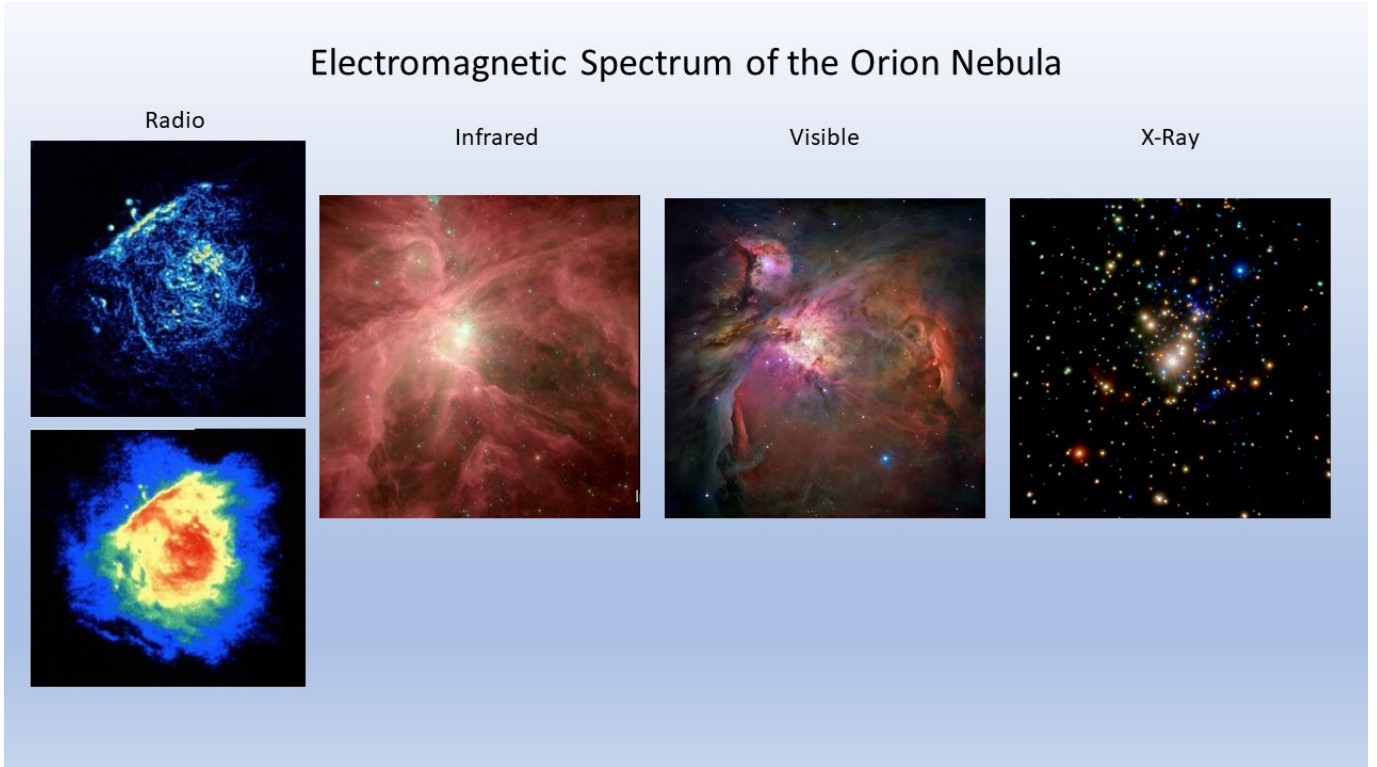


Figure 4. A comparison of the Orion Nebula at different wavelengths. Credit: NASA/AUI/CXC

0.148 and up to 0.19. This is particularly interesting since figure 5 shows that the noise continues a bit further in the range of magnitude and there actually may be more noise with higher magnitudes with a peak around 1 and a peak around 2. Another reason as to why this is interesting is because officially, the magnitude of the Orion Nebula is of 4. This means that the CCD is actually detecting the Nebula at a higher magnitude. With our selection being so precise, it also means that most of these peaks are purely noise, and in order to get the best image, we must take a look at the underlying data while making sure not to select any of the peaks in noise. In the end, it was determined that the magnitude range between 0.148 and 0.19, after the image calibration, was the most effective at selecting the most relevant data for the image.

4.2. Comparing our Results to the Literature

As we are photographing the Orion Nebula, it is very appropriate to compare our image with the known literature and highest quality photographs. We can start by comparing the brightness and amount of detail in each image. If we compare our photograph, with the one taken by Hubble in figure 1, we see that there is much more detail in the Hubble picture compared to our own. This is due to various things but can in part be attributed to Hubble's primary mirror being much larger

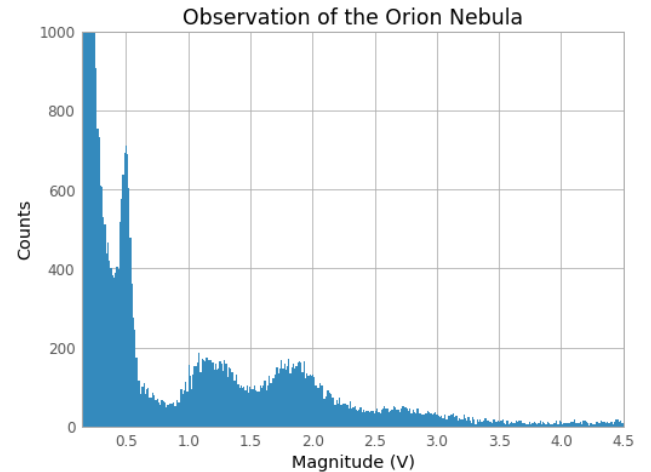


Figure 5. When zoomed in to the histogram, we can clearly see more structure in the noise, which helps determine which magnitudes are the best to include in the image in order to reduce the noise.

(around 93.6 in) (Meylan et al. 2004), compared to our own telescope of 14in. Another aspect is that Hubble is located in space compared to our own telescope being located in the heart of Morgantown. This means that not only are Hubble images not affected by light pollution, but they are also not affected by the atmosphere, which is something that starts to greatly affect results

when objects are very low on the horizon, as discussed in previous sections.

If we analyse the shape of the clouds however, we see that it is relatively similar to what we would expect, however, it is not as bright, there are not as many details and it is not oriented in the same way. Just by looking at the images in figure 1 and figure 3 one can easily recognize the gas formations and determine that we have successfully captured the gas clouds in the Orion Nebula.

An important difference between the image taken in this project and the images normally taken is astrophotography, is that we were only working with 1 filter. Normally, there are many filters of different colors, which will capture certain wavelengths of light and can later be combined to create a “True” color image (Ceravolo 2011). The colors seen in figure 3 are not colors which the eye would see, but rather only show the intensity of the light coming from those sources. This means that the colors between our photo and a typical photo of the Orion Nebula are not related and signify completely different things. In an ideal environment, we would have been able to take 3 different pictures, using red, green and blue filters respectively, however our current setup did not allow us to do this in a simple enough matter to be inside the scope of the difficulty level for this course.

Another interesting point of discussion is that the image we took was at visible wavelengths, however, the Orion Nebula is visible at many other wavelengths, including the extremes of radio and x-ray detection. We

can see in figure 4, a clear comparison of images at different wavelengths, which makes it easy to understand that although our image is a relatively good representation of the visual wavelengths at which it was observed, it does not show all aspects of the Nebula which are visible throughout the electromagnetic spectrum. The infrared and optical spectrum photos are particularly good at detecting different gases, mostly HII gas (Weilbacher, Peter M. et al. 2015), and show the wide range of the nebula whereas the radio images show somewhat smaller and different detection, and the x-ray image captures photons from more extreme objects such as stars and supernovae.

5. CONCLUSION

In this project, we were able to successfully create an image of the Orion Nebula and complete a calibration which eliminated most noise. We then compared the image to literature, and discussed the single range of wavelengths observed, and how they differ from other possible wavelengths. Future work includes adjusting the camera settings to create a better image quality, and taking multiple CCD images in different color filters to create a more accurate and realistic depiction of the observed color.

6. ACKNOWLEDGEMENTS

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APPENDIX

Facilities: White Hall Observatory

Software: astropy (Astropy Collaboration et al. 2013; Price-Whelan et al. 2018), numpy (Harris et al. 2020), matplotlib (Hunter 2007), pandas (Wes McKinney 2010; Reback et al. 2021)

REFERENCES

- Astropy Collaboration, Robitaille, T. P., Tollerud, E. J., et al. 2013, *Astronomy & Astrophysics*, 558, A33, doi: [10.1051/0004-6361/201322068](https://doi.org/10.1051/0004-6361/201322068)
- Ben-Jaffel, L., & Ballester, G. E. 2013, *Astronomy Astrophysics*, 553, A52, doi: [10.1051/0004-6361/201221014](https://doi.org/10.1051/0004-6361/201221014)
- Berriman, G. B., Gelino, C. R., Goodrich, R. W., et al. 2014, *Software and Cyberinfrastructure for Astronomy III*, doi: [10.1117/12.2054772](https://doi.org/10.1117/12.2054772)
- Ceravolo, D. 2011, *Society for Astronomical Sciences Annual Symposium*, 30, 13
- Frommert, H. 2009, NGC 1976 = M42. <http://spider.seds.org/ngc/ngc.cgi?NGC+1976>
- Harris, C. R., Millman, K. J., van der Walt, S. J., et al. 2020, *Nature*, 585, 357, doi: [10.1038/s41586-020-2649-2](https://doi.org/10.1038/s41586-020-2649-2)
- Hunter, J. D. 2007, *Computing in Science & Engineering*, 9, 90, doi: [10.1109/MCSE.2007.55](https://doi.org/10.1109/MCSE.2007.55)
- Meylan, G., Madrid, J., & Macchetto, D. 2004, *Publications of the Astronomical Society of the Pacific*, 116, 790. <http://www.jstor.org/stable/10.1086/423227>

- Price-Whelan, A. M., Sipőcz, B. M., Günther, H. M., et al. 2018, *The Astronomical Journal*, 156, 123, doi: [10.3847/1538-3881/aabc4f](https://doi.org/10.3847/1538-3881/aabc4f)
- Reback, J., McKinney, W., Jbrockmendel, et al. 2021, *pandas-dev/pandas: Pandas 1.2.1*, Zenodo, doi: [10.5281/ZENODO.3509134](https://doi.org/10.5281/ZENODO.3509134)
- Reid, M. J., Menten, K. M., Zheng, X. W., et al. 2009, *The Astrophysical Journal*, 700, 137–148, doi: [10.1088/0004-637x/700/1/137](https://doi.org/10.1088/0004-637x/700/1/137)
- Weilbacher, Peter M., Monreal-Ibero, Ana, Kollatschny, Wolfram, et al. 2015, *A&A*, 582, A114, doi: [10.1051/0004-6361/201526529](https://doi.org/10.1051/0004-6361/201526529)
- Wes McKinney. 2010, in *Proceedings of the 9th Python in Science Conference*, ed. Stéfan van der Walt & Jarrod Millman, 56 – 61, doi: [10.25080/Majora-92bf1922-00a](https://doi.org/10.25080/Majora-92bf1922-00a)
- Whitelock, P., & Oluseyi, H. M. 2008, *AIP Conference Proceedings*, doi: [10.1063/1.2905138](https://doi.org/10.1063/1.2905138)