Collisional Ionization in the Interstellar Medium

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Abstract

The Collisional Ionization region NGC 2440 was analyzed in H alpha, OIII, SII, and V band filters. From the data a RGB image was created using Halpha, OIII, and SII. The image turned out well with no misalignment due to the WCS coordinates obtained from astrometry.net. Next the structure of the collisional ionization region was looked at. Overall RGB image NGC 2440 displayed a shape of two crossing ellipses. In the H-alpha image (red) we were able to capture two crossing ellipses, one bright and one dim. Next in the OIII image (green) the structure was in the shape of an ellipse however it was dominated by a bright circular center. For SII region displayed a ellipse shape but much smaller in size relative to H-alpha and OIII. Lastly the proportion of emission for H-alpha, OIII, and SII can be approximated by the brightness count ratio 8000:12000:500.

Introduction

Collisional Ionization region occurs when electrons in an interstellar medium moves fast enough to ionizes the surrounding gas molecules. These region typically can be found in planetary nebula's, which occurs when a red giant star ejects the outer layer leaving a white dwarf core. In these regions OIII lines are much stronger than H-alpha line which usually is the opposite case in HII regions (Arora Waterloo). In this experiment we focus on emission lines of H alpha, OIII, and SII and also the V band. The theory behind these lines are as follows: the electron that orbits the atom can be energized to a higher state by a fast moving free electron with a specific kinetic energy. The kinetic energy of the electron depends on the energy gap between the two energy levels. Once the electron is at a higher state it would eventually decay back to a more stable state and thus releases a photon with energy equal to the initial free electron that collided. We can detect these specific photon energy as H alpha or OIII lines which gives us an insight on what the cloud is made up of. To find emission lines we used the observatory located on top of the Physics building of The University of Waterloo. The Observatory consist a 14" Celestron Telescope with 3.91m focal length. (Fich 2016)

Observational Method

The observatory is located at longitude: -80.541^o and latitude: 43.4706 North with elevation: 340m (Fich 2016). The target for the lab was NGC 2440 with the central star HD 62166. The logic behind picking NGC 2440 was that NGC 2440 is a large and bright planetary nebula that can be easily observed during the winter. The object is in the SkyX database so locating it didn't require a skychart. NGC 2440 is known as the "Albino Butterfly" the unique shape would give us a foundation for our data to try to explain the shape. On the night of observation the skies were clear and temperature outside was -2^o Celsius. Once the object was located we began to take images with 3x3 binning. We decided to use 3x3 binning instead of 1x1 or 2x2 is because we wanted the image to have a sharper focus and also less noise. Since the nebula NGC 2440 was bright enough there was no need to use 1x1 binning so a higher binning was used to reduce the noise. Reducing the noise would be important especially for SII where the photon count is low so reducing the amount of noise is critical. We proceeded to take H alpha (656.46nm), OIII(436.44nm), SII(407.23nm), and V band in that order. For each filter we took three different exposure times: 100s, 10s, and 1s. The purpose of choosing 100s is that beyond 100s the objects in the image would start to drift. As a result the stars become more like a streak instead of a point like object.

Analysis

Part A

To create the RGB picture the program AstroImagej was used. The process was as follows: first load the three filters Halpha, OIII, and SII into the program. The 100s exposure time was used since the 10s and 1s weren't long enough to get a clear image or distinguish any features of NGC 2440. Then a stack of three images was created. From there I created a composite color image under the color tab. This is where I was able to adjust the contrast for each image. The H alpha is colored in red, OIII in green and SII in blue. Lastly once all the brightness and contrast is set, the image is smoothed so there is less pixelation on the image. Finally the result can be seen below:

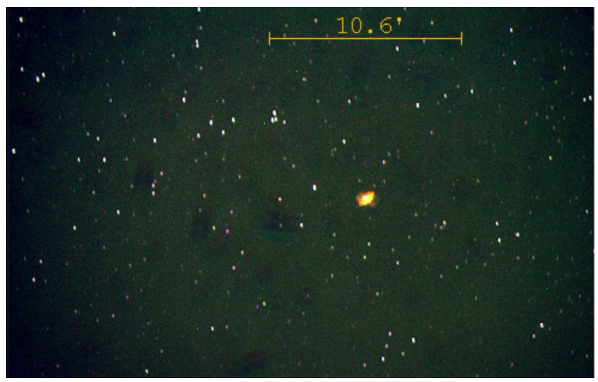

Figure 1: RGB Image of H alpha (red), OIII (green), and SII (blue)

NGC 2440 can be seen as the red-orange structure near the center of the image. The image turned out pretty well there was no offset in the wcs coordinates. As a result when the three images were stacked the stars didn't produce misalignment. Without the files in wcs then the images would be completely out of sync and for each star there would be a red, green, and blue copies.

Next a discussion would be made about the object in a Vband image. Compared to the individual H-alpha, OIII, and SII filters the V band image had a lot more activity. This is because the other three filters only took in light from a narrow length however V band takes in photons between 500nm to 700nm as a result it captures a lot more information:

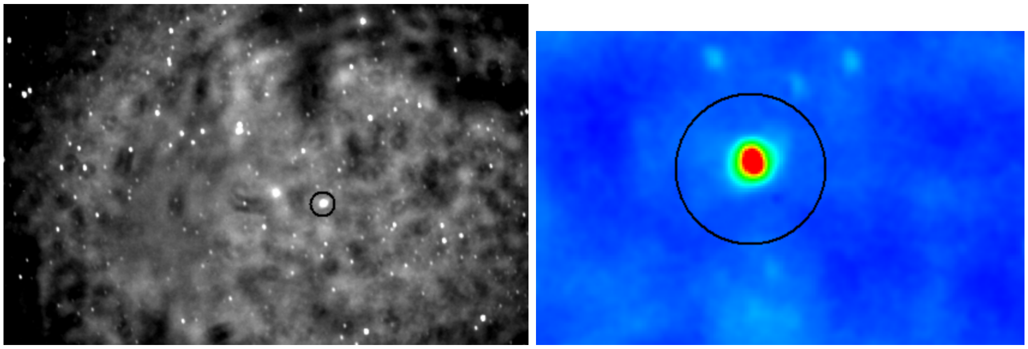

Figure 2: V band Image: Grey Color of Entire image (left) and NGC 2440(Right). NGC 2440 can be located within the black circle in both images.

From the image on the right the zoomed in picture of NGC 2440 we see that in the V-band the shape is almost circular. As oppose to the RGB image of figure 1 where it has more of a two crossing ellipse shape. The reason why this might be because the V-band captures both wavelengths of H-alpha and OIII spectrums, this results in the shape evening out into a sphere in the V-band.

Part B

The main purpose of this analysis is to first understand the underlying structure of the H alpha, OIII, and SII in NGC 2440. Second to determine the ratio of the emission lines along various directions. The method used would be as follows: the image below is the RGB function used in DS9. Where the H alpha is the red, OIII is the green, and SII is blue.

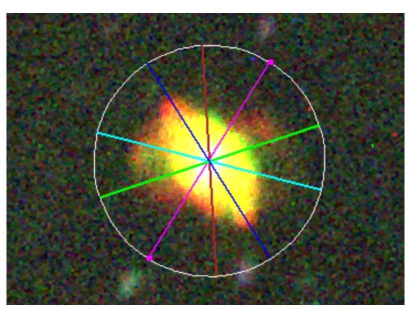

Figure 3: DS9 RGB Image of H alpha (red), OIII (green), and SII (blue) with Circular and line regions

There are two key regions in figure 3, first is the circle and the other is the five lines with equal length. The main purpose of the circle is to make sure the lines that cross nebula are all of equal length. Within the large circle is a much smaller circle in the center this makes it so every line that cross the center circle would cut the circle perpendicularly. The center of the large circle was decided by approximating by eyes where the center NGC 2440 is. By inspection the shape of NGC 2440 seem to be of a bright ellipse with it's major axis on the blue line and a dimmer ellipse with it's major axis between the cyan and green line. Later on the in the analysis there will be a more in-depth look into the shape of NGC 2440 within the three filers. Next the lines are mainly used to determine the ratio of emission between the three filters. In DS9 the "Plot 2D" of the analysis tab for the line gives a number of count along the length of the line. This function would give a sense of emission proportion between the three filters.

The ratio of emission between the three filters would be looked at first. Below (figure 5) are five graphs representing the five different line seen in the figure 1: blue, cyan, green, purple, and red. The red line in the graphs is the H alpha brightness and the green and blue is the OII and SII respectively. From the five graph we get a very consistent trend of OIII having the highest count with H alpha and SII trailing in that order. This is consistent with the theory that within planetary nebula's the OIII lines are much stronger than the H-alpha lines. The H-alpha lines peak around 8000 counts in the five graphs while OIII peaks at 12000+ counts and for SII around 500. These values gives an approximation on the emission proportions between the three filters. From these fives graphs the cyan, green, and purple that OIII is larger than H-alpha in the areas that the three lines cover. This is because the OIII bell-curve has a larger base than the H-alpha curve. Since all the lines are equal lengths then a larger base suggest that there are more OIII that is captured by the line than H-alpha.

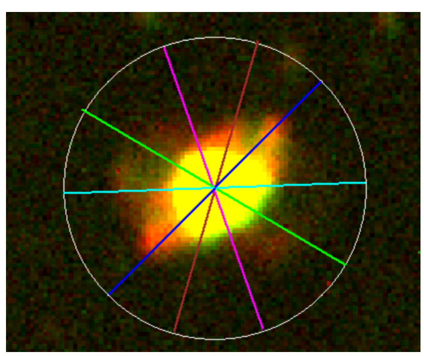

Figure 4: DS9 Red and Green Image of H alpha (red), OIII (green)

We can see that the areas that cyan, green, and purple covers also corresponds with the area that the OIII (green) is larger than the H-alpha(red) area. Next section we would provide a more in-depth analysis on the shape of the region.

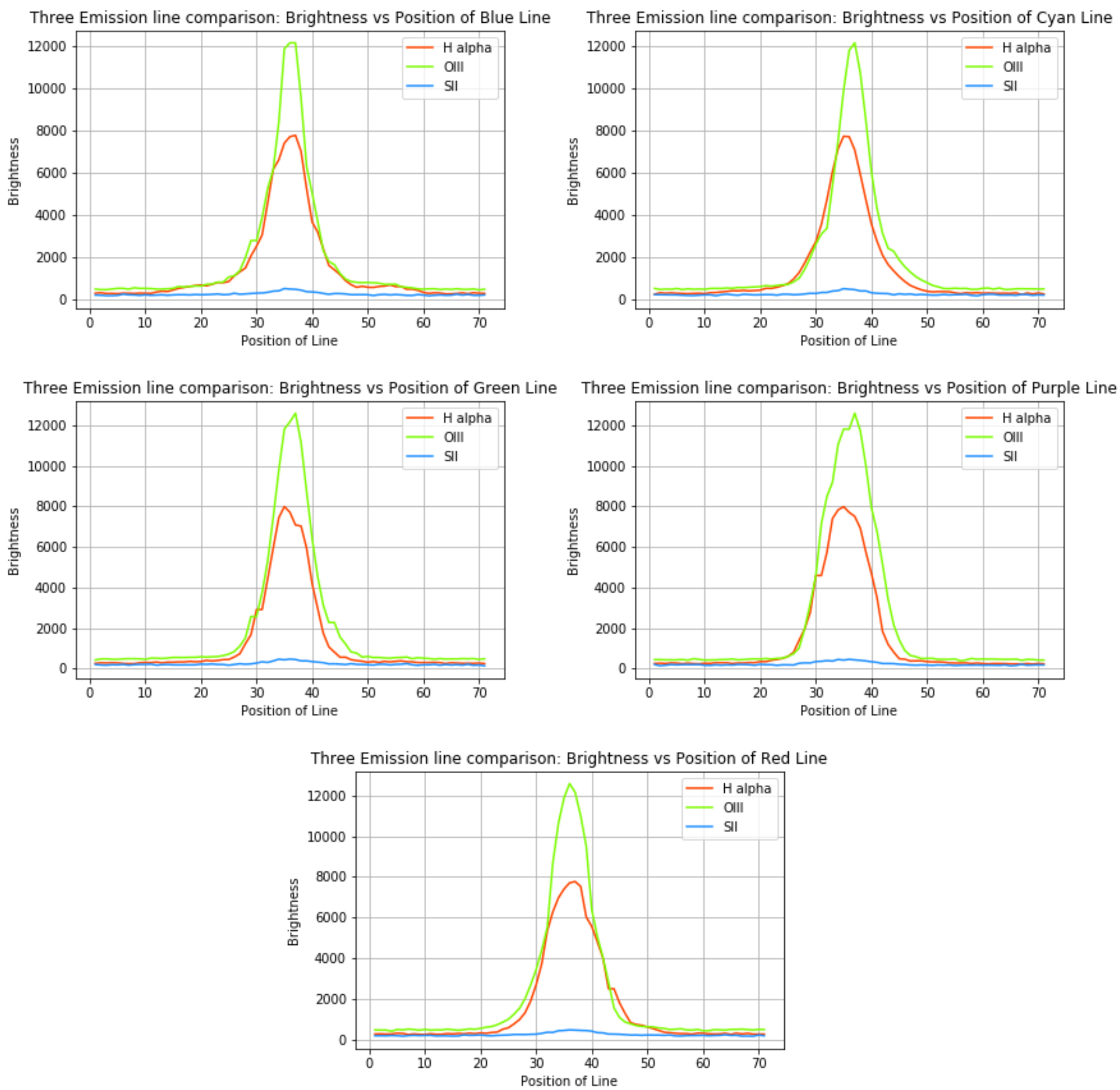

Figure 5: Emission line comparison of H alpha, OIII, and SII filters

The next step is to determine the general shape of each region. In figure 6 each graph represents the five lines in the three filters: H alpha, OIII, and SII in that order. For each graph the color of the curve represents the brightness count for each line in the image of figure (3). For example in the H-alpha graph the five different color curves represent one of the color lines in the H alpha filter. The purpose of these plots is to give a sense of the shape of each region. Since the lines are in various direction if the shape is circular the shape of the curves would be Gaussian where the size of the bases are almost equal to each other however if the shape is more ellipse than one of the lines would have a larger base than the other since it corresponds to the major axis of the ellipse. This was talked about briefly in the analysis discussion of emission proportions. Overall the three graphs agrees with the graphs in figure 5, where the peak of H-alpha is around 8000, OIII around 12000, and SII around 450-500. The main reason that H-alpha and OIII has much smoother curves is because the brightness counts are much higher than the SII. Since SII is much dimmer than the effect of noise plays a much bigger role. As a result the SII graph seems to be much more jagged and rough.

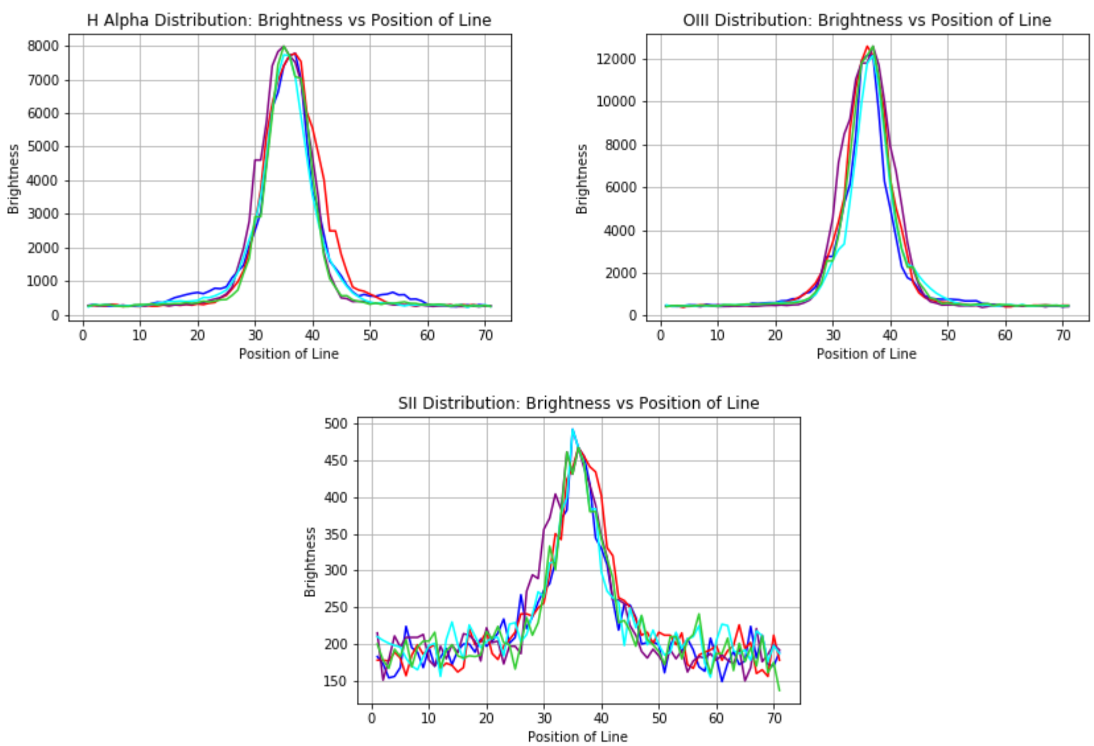

Figure 6: Distribution of brightness along the four lines of H alpha, OIII, and SII.

Now to tackle the shape and offset in position of the various regions. First is to split the RGB image into it's three colors:

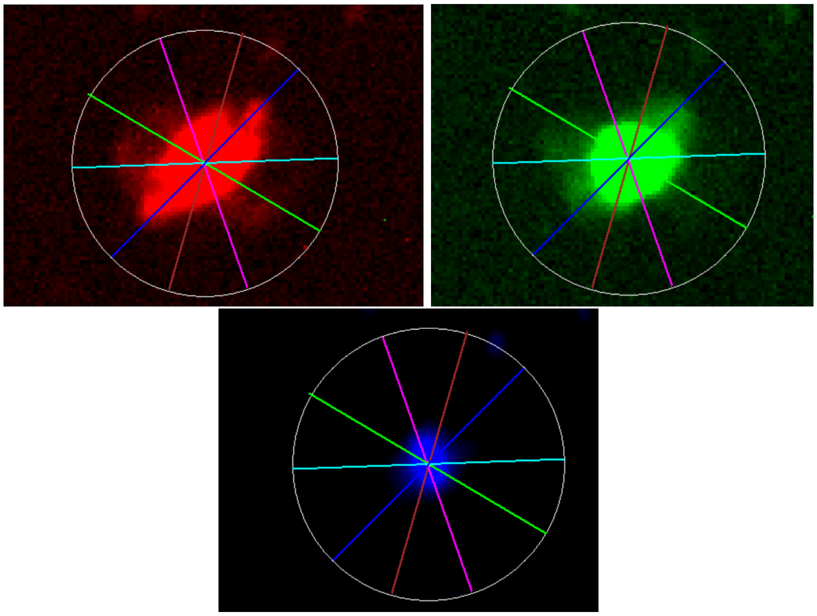

Figure 7: RGB Image Split into Red (H-alpha), Green (OIII), and Blue (SII).

By inspection it seems that the H-alpha consist of a two ellipses one bright and the other much dimmer. The major axis of the bright one corresponds approximately with the blue line and the dim one with green or cyan line. In the OIII image it seems to be approximately the shape of an ellipse however the brightest parts forms a circular structure. Lastly SII has a evenly distributed ellipse with the purple line in the direction of the major axis.

First for the H-alpha graphs from the plots of figure 6 the curves of the blue line should have a thicker base than the one of the green since the blue line is the major axis for the bright ellipse and the green line is the approximate minor axis. Plotting just the blue and green line yields:

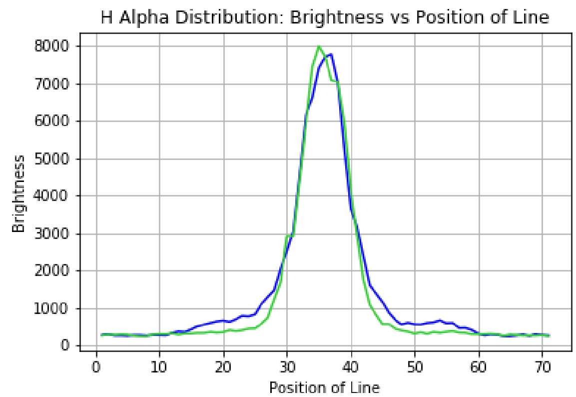

Figure 8: H-alpha blue and green line.

Which is what we expected with the blue line having a larger base than the green one. As for the dimmer ellipse it difficult to determine the exist of it other than by inspection since the brighter ellipse dominates the image so much it's difficult to determine where the dim ellipse begins and where it ends on the green line.

Next for the OIII structures looking at figure 7 again the blue line should have a larger base than the green.

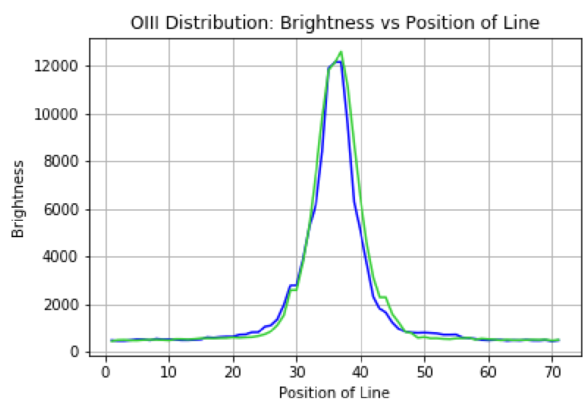

Figure 9: H-alpha blue and green line.

From figure 9 we see what we expected, the blue curve is larger when the x-axis is from 20 to 30 and 50 to 55. The reason why it's not as noticeably larger as in figure 8 is because the brightest parts of OIII is the sphere in the center and the reason why the blue curve is wider is due to the dimmer ends of the ellipse. This can be seen in figure 7 of the OIII image. We see that both blue and green cross the central bright circle but blue also picks up the extra counts near both ends due to the ellipse nature of the region. Finally a look at the OIII distribution in figure 6 we see that all five lines have curves that are similar in shape which suggest that the brighest part of OIII region is ciruclar in shape. However it seems that the purple line is the widest out of the five by a small margin so this might suggest small bit of eccentricity.

Lastly is to look at the SII structures. In figure 7 it suggests that SII region has a ellipse shape with purple being in the direction of the major axis and cyan being the minor axis. As a result the graph below is of cyan and purple.

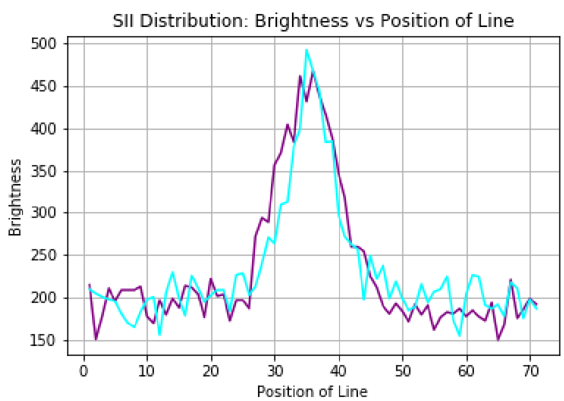

Figure 10: H-alpha blue and green line.

Although it's little bit tougher to determine with the noise in SII we see that the purple line overall is wider than the cyan line. This is consistent with bean shape of SII from inspection.

In terms of the position of three structures they are all centered around a point. Since NGC 2440 is a planetary nebula the center point surrounds the central star HD62166.

Finally the results can be compared to images that others have done of NGC 2440. An image of NGC 2440 done by Jeff Cremer can be seen below(Cremer, 2003)

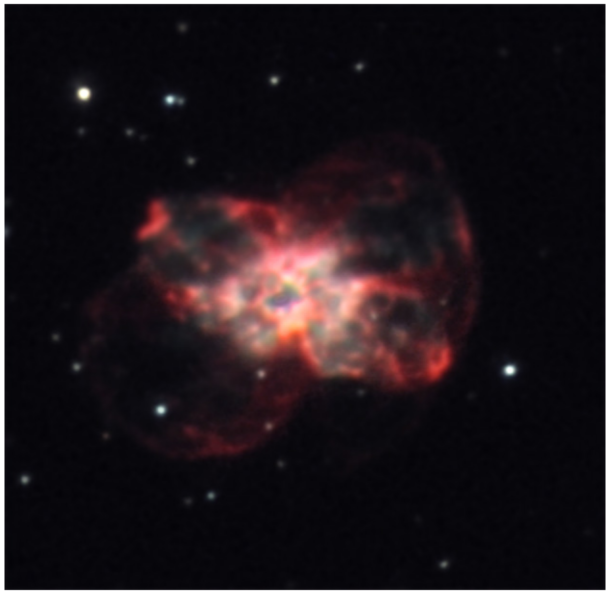

Figure 11: Image of NGC 2440 by Jeff Cremer.

Comparing this with our image figure 3 we can see similar features. From the image done by Jeff Cremer we see the two ellipse structures one bright and one dim. We were also able to capture the two ellipse in our image. Note in figure 3 our image is flipped on the y-axis as compared to Cremer's image. We were also able to capture the bright center of the nebula. In our case we saw a circular bright center which can be seen in Cremer's image where the ellipse is red the center of the ellipse has a white circular structure.

Conclusion

To conclude the purpose of observing NGC 2440 is to first create a RGB image using H alpha, OIII, and SI filters; second to understand the structure and ratio of emission of the three lines. From the images we were able to create an RGB image using the AstroImageJ program. The image came out well after using the WCS coordinates from astrometry.net, there were no misalignments of the images. Next to analyze the structure of the collisional ionization region we created multiple lines spanning across the NGC 2440 in different directions and in DS9 found the brightness/count versus the length of the line. From this we were able to determine that H-alpha exhibited 2 crossing ellipses structure with one bright and the other. As for OIII it had an overall ellipse shape however it's center is dominated by a bright circular center. Lastly SII was determined to be a bean shape ellipse but with a much smaller size compared to H-alpha and OIII's structure. Finally it was discovered that in the collisional ionization region OIII was the brightest with H-alpha and SII trailing in that order. The brightness count ratio between OIII, H-alpha, and SII is approximately 12000:8000:500.

References

(Cremer 2003) Cremer J. 2003. NGC 2440 .Online. http://www.caelumobservatory.com/obs/n2440.html

(Fich 2016) Fich, Mike.2016. Observing Manual. Phys 370L. Waterloo (On): University of Waterloo.

(Arora Waterloo) Arora, Victor. n.d. ollisional Ionization in the Interstellar Medium. Waterloo (On): University of Waterloo.