PHYS100/301 Lab 3: Spectrum of the Cat’s Eye Nebula

Eric Yue Ma, Hans Henken, Jake Zeller, Franklin Liou, Kevin Laube

1. Abstract

We characterize the spectrum of the Cat’s Eye Nebula. Using He, Ne, and Hg lamps to calibrate our spectrum dispersion, we identify numerous spectral lines by comparing collected data with a table of wavelengths emitted by common elements. We observe emission lines from H, C, He, N, Si, Ar, O, S, and possibly Hg in the nebula and discuss why the composition of the nebula could be important to life on earth.

2. Target, Equipment, and Methods

The 24 inch telescope in the student observatory was used in conjunction with the spectrograph and spectroscopy CCD to characterize the spectrum of the Cat’s Eye Nebula. Before imaging the spectrum, the nebula was located using J2000 coordinates and exposures were taken using the imaging CCD (Apogee AP8) to make sure the telescope was properly positioned. We used images from the DSS2 red survey to accurately confirm the location by matching specific and noticeable stars in the field of view.

After the nebula was located using the imaging camera, we switched to the slit viewer and positioned the nebula in the center of the slit. The spectrograph CCD was cooled to its normal temperature of -40 centigrade, and we took multiple 4 minute exposures through the slit viewer, changing the position of the slit with each image in order to characterize the spectrum of the entire nebula (not just the center star).

To take color images, we used the same 24 inch telescope with Apogee AP8 imaging camera. As before, the nebula was located using J2000 coordinates and the camera was cooled to its normal temperature of -40 centigrade. We used images from the DSS2 red survey to accurately confirm the location of the nebula. A clear image was taken with 60 second exposure time, and images with red, green, and blue filters were each taken with 180 second exposure time. We were careful not to saturate the images. Bias and dark frames were taken at the end of each night, which were later subtracted from the final images to improve quality of the combined exposure.

The observation details are summarized in table below.

Date and time	Conditions	Target ID	Equipment	Exposure
5/15/13	Full moon, high	Cat’s Eye	Spectrograph	7 x 4 minutes

10:30 PM	sky brightness	Nebula		
5/15/13 11:00 PM	Full moon, high sky brightness	Cat's Eye Nebula	Spectrograph, bias frame	0 seconds
5/15/13 11:00 PM	Full moon, high sky brightness	Cat's Eye Nebula	Spectrograph, dark frame	60 seconds
5/22/13 10:30 PM	Half moon, clear	Cat's Eye Nebula	Imaging CCD, no filter	60 seconds
5/22/13 10:32 PM	Half moon, clear	Cat's Eye Nebula	Imaging CCD, red filter	180 seconds
5/22/13 10:36 PM	Half moon, clear	Cat's Eye Nebula	Imaging CCD, green filter	180 seconds
5/22/13 10:40 PM	Half moon, clear	Cat's Eye Nebula	Imaging CCD, blue filter	180 seconds
5/22/13 10:45 PM	Half moon, clear	Cat's Eye Nebula	Imaging CCD, bias frame	0 seconds
5/22/13 10:45 PM	Half moon, clear	Cat's Eye Nebula	Imaging CCD, dark frame	60 seconds
5/22/13 11:00 PM	Half moon, clear	Cat's Eye Nebula	Spectrograph	3 x 4 min
5/22/13 11:15 PM	Half moon, clear	Cat's Eye Nebula	Spectrograph, bias frame	0 seconds
5/22/13 11:15 PM	Half moon, clear	Cat's Eye Nebula	Spectrograph, dark frame	60 seconds

The process spanned over three weeks, with the first two weeks devoted to observations and the third week data analysis. During our first observational session, we had a full moon which greatly affected the FWHM of our images and made focusing difficult. Accordingly, we devoted this session to spectroscopy exclusively. During our second observation session, the half moon improved FWHM to between 4 and 5 pixels. We took color images and spectrum images during this session. Dark and bias frames were subtracted from our original exposures. Spectrum images were processed in IRAF and clear/filter images were combined in Maxim to create an overall image of the Cat's Eye Nebula.

3. Results and Analysis

Image of the nebula

Fig. 1 is a color combined image of the Cat's Eye Nebula constructed using three 180 second frames we took in the R, G, B filter. The structure of the nebula, including the center star is clearly visible and we can therefore take spectrum of different parts of the nebula.

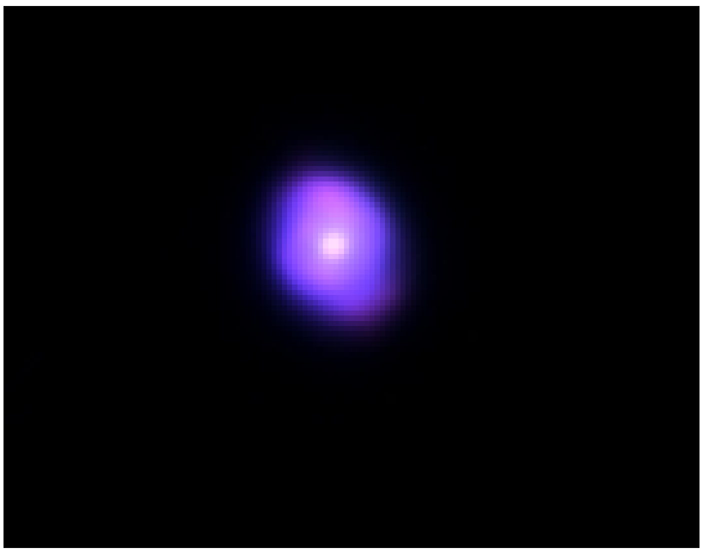

Fig. 1. Combined RGB image of the Cat's Eye Nebula

CCD Calibration

In order to get the accurate mapping from CCD mapping to actual wavelengths, we took the spectrum of 3 standard calibration lamps: He, Hg and Ne. The peaks identified from the spectra are listed in the 3 tables below and plotted in Figure 2.

He:

wavelength (nm)	504.774	587.562	667.875
pixels	24.16	245.29	453.58

Hg:

wavelength (nm)	546.074	576.959	579.065
pixels	139.00	218.52	223.85

Ne:

wavelength (nm)	585.249	594.483	607.434	609.616	614.306	626.649	638.299
pixels	239.53	263.38	296.92	302.59	314.77	346.86	377.15

nm	640.225	650.653	659.895	667.828	671.704
pixels	382.22	409.37	433.41	454.22	464.17

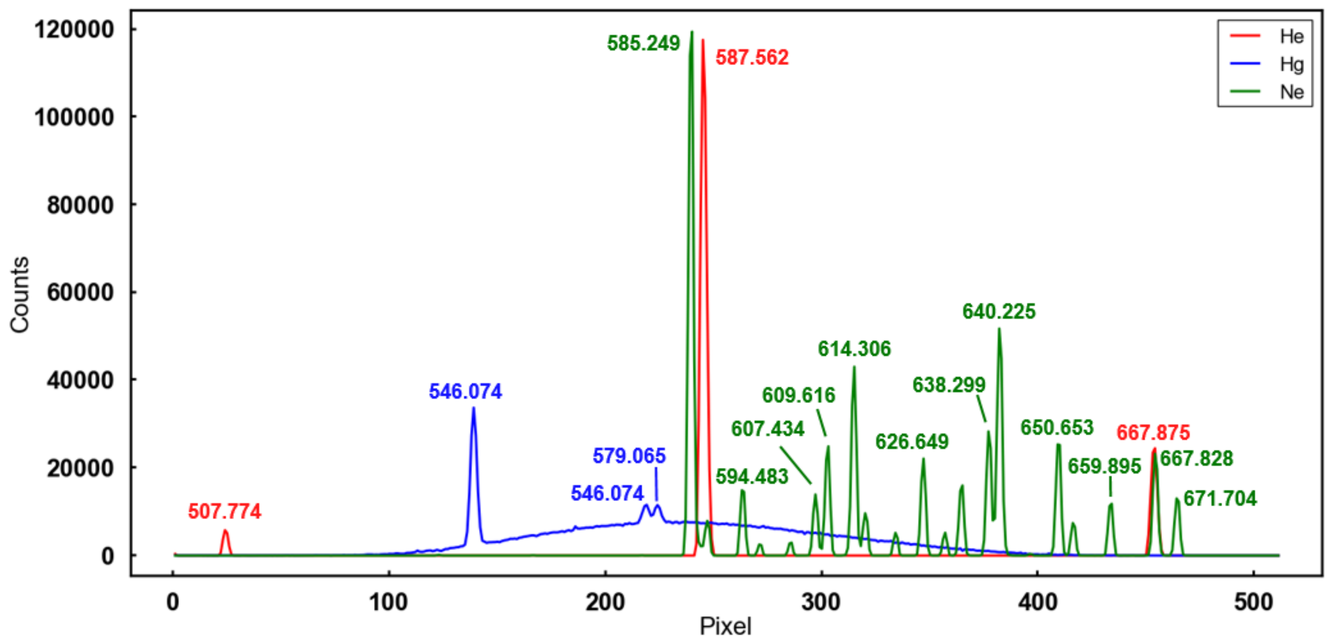

Fig. 2. Emission lines identified from He, Hg and Ne lamp calibration frames.

In order to calibrate the positions of the observed lines on the CCD to actual wavelengths, we plotted the positions of the lines observed from the He, Ne, Hg lamps and their known wavelengths. We then used a second-order polynomial fit to obtain our conversion formula:

$$y = 2.25312675\times10^{-5}x^2 + 3.70285443\times10^{-1}x + 4.95257102\times10^{2}$$

where *y* is the wavelength in nanometers and *x* is the position in pixels. The second order term is small, so the correspondence between position and wavelength is very linear, as expected. The range in wavelength of the CCD is 495 - 690 nm, with 0.38 nm/pix. We then used the calibration to identify the wavelengths of emission and absorption features in our data from the Cat's Eye Nebula.

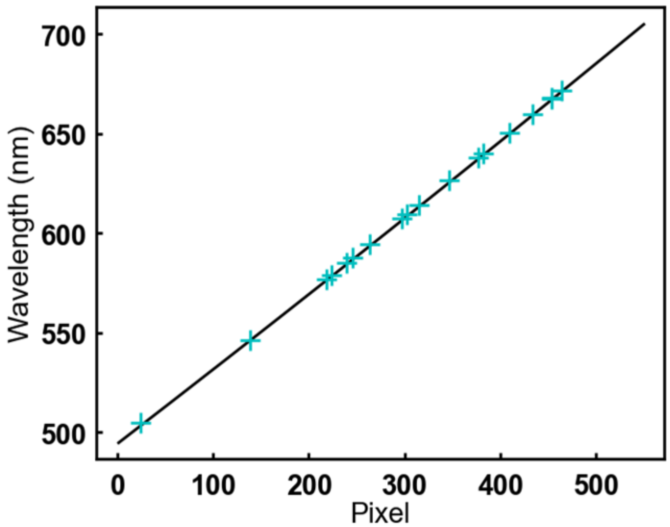

Fig. 3. 2nd order polynomial fit of wavelength vs. pixel, showing good linearity.

Spectrum of Cat's Eye Nebula

Easily visible emission lines observed at the top of the nebula are summarized in the following table. The elements we identified are listed at the top of each observed wavelength.

Series	OIII	OIII	Hg ???	HeI	H_alpha	NII	HeI	SII	SII
Nominal wavelength (nm)	495.89	500.68		587.56	656.28	658.35	667.88	671.65	673.09
Extracted wavelength (nm)	498.55	503.09	546.50	586.95	655.46	657.46	667.21	670.72	672.36

Figure 4 below shows the observed spectrum at the top of the nebula.

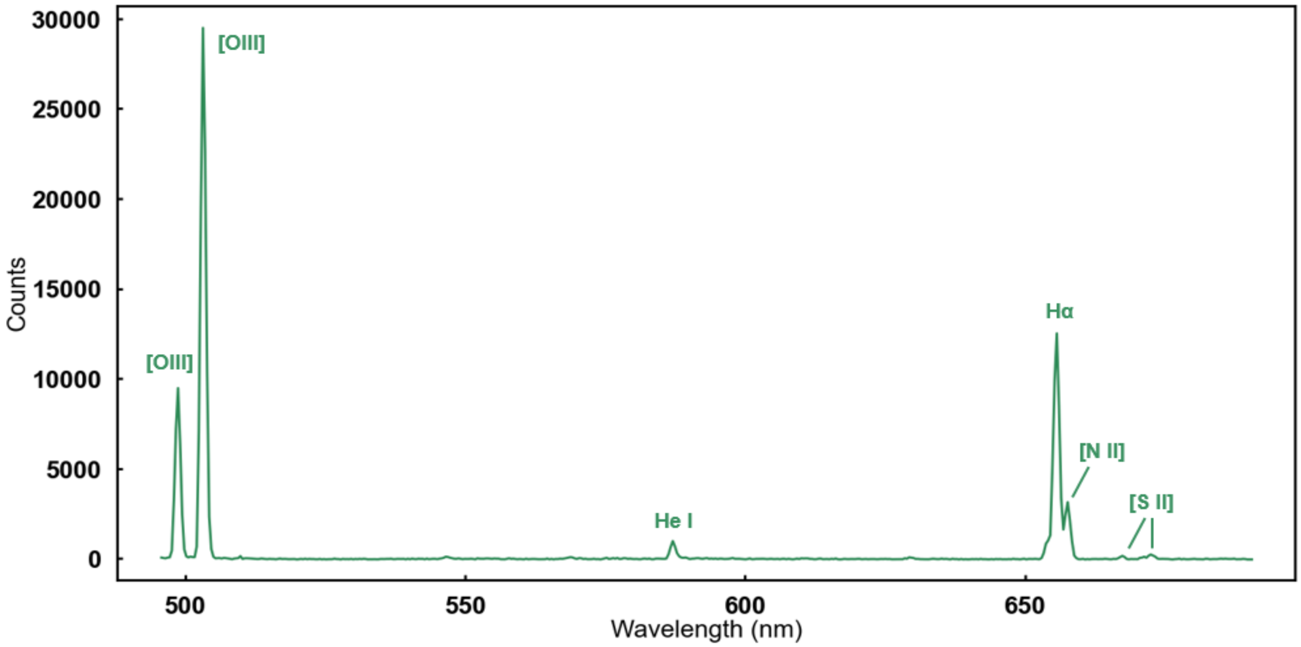

Fig. 4. Spectrum of the top part of the nebula, several common elements found in planetary nebulae are easily identified.

<u>Comparing the center and the top region</u>

Easily visible emission lines observed at the center of the nebula are summarized in the following table. E indicates an emission line, A indicates absorption.

Series	Si II (A)	C II (E)	Ar III (E)	N II (E)	C IV (E)	O I (E)
Nominal Wavelength (nm)	505.6	512.18	519.16	568.6	580.11	630.05
Extracted Wavelength (nm)	507.5	510.47	517.18	568.3	579.71	621.15

Figure 5 below plots the observed spectrum at the top of the nebula and the center of the nebula.

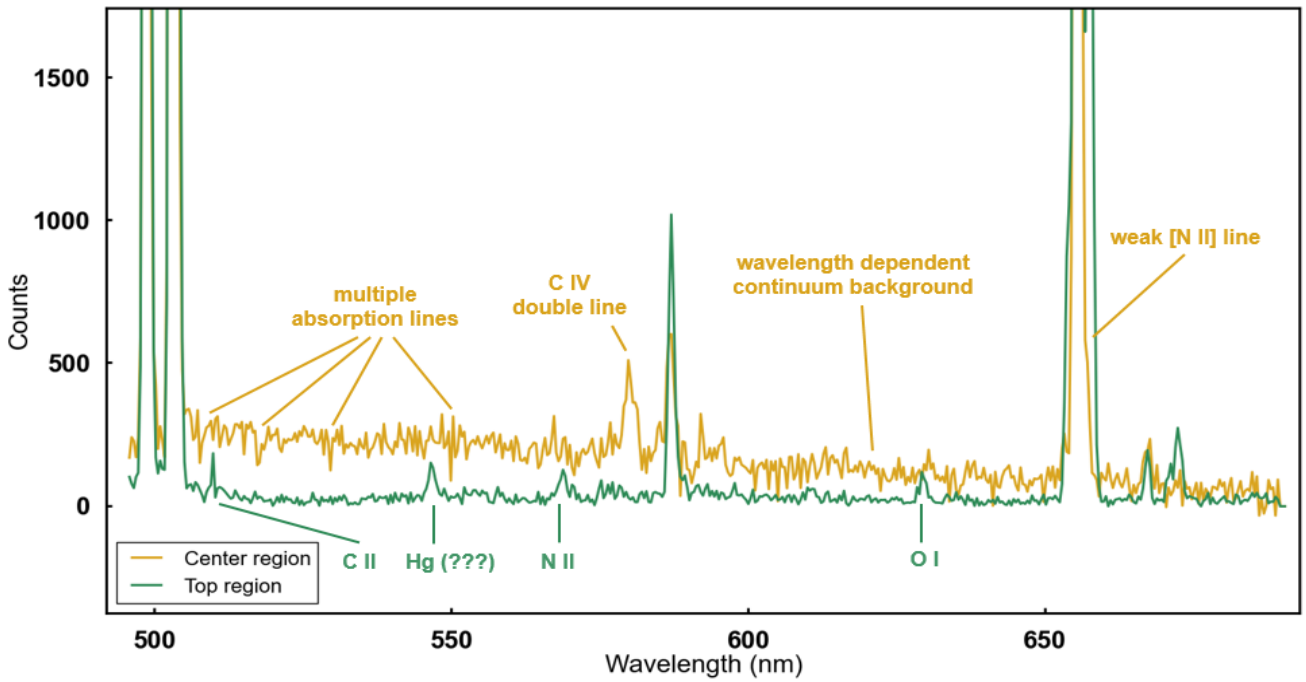

Fig. 5. Comparison of the top and center part of the nebula. The continuum of the center star is clearly visible. Several smaller emission lines from the top region are also identified.

The spectra of the center region exhibits a wavelength dependent continuum of radiation. The continuum is nearly monotonic in wavelength, indicating that the star could be very hot and we are seeing the tail of its blackbody radiation. It also has some indistinct absorption features which, if using better instrument and taking longer exposures, can tell us about the composition of the star's atmosphere and the nebula nearest to the star. In comparison, the top region has only a few emission features with a low background. In the center region, we observe a strong C IV double line which is not present in the top region of the nebula. This indicates that high energy photons are present near the center of the nebula, which stripped four electrons from the Carbon. In the top region, we observe an emission line at 546.5nm, which we speculate to be Mercury (although in theory we should not be able to find mercury, which is heavier than Fe, in the planetary nebulae).

4. Conclusions

As shown above, H, C, He, N, Si, Ar, O, S, and possibly Hg are present in the Cat's Eye Nebula. The presence of highly ionized species indicates that the central star is very hot, which is a signature of intense nuclear reactions leading to the creation of heavy elements.

From our analysis, we have found evidence that planetary nebula, such as the Cat's Eye Nebula, are capable of producing heavier elements (metal) which can be vital for life, especially C, which is found only near the center of the nebula. This evidence points to a greater importance that planetary nebula may play in the creation and distribution of elements across galaxies.

5. References

"The optical spectrum of the planetary nebula NGC 6543", S. Hyung et. al., *MNRAS (2000) 318(1): 77-91 doi:10.1046/j.1365-8711.2000.03642.x*