Image Analysis of Planetary Nebula
NGC 6543

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PLANETARY NEBULAE

A star is a sphere of gas where the gravitational force that pulls all particles together, is balanced by an outgoing pressure from the gas itself. When a low mass star like the sun or a few times more massive than the sun burns more and more heavy elements, it makes its final lap across the Hertzsprung-Russell (H-R) diagram and enters a region called asymptotic giant branch (AGB), a region that lies above and parallel to the red giant region. In the AGB region, the star, which has expanded into a red giant, continues to go through a series of changes as its dying process continues. Inside the core of the star, there is a carbon ash core, a shell where helium is fusing into carbon, and a shell where the fusion of hydrogen to helium has temporarily ceased. As the fusing of helium into carbon continues, the inner core collapses to a high-density state causing the burning inside the shell to increase its intensity. At this point, the star becomes unstable, continues to heat up, and begins shrinking, as it becomes a white dwarf. Inside the core, nuclear reactions are taking place such that carbon, nitrogen, and oxygen are created. Through convection, these reactions are transported to the outer envelope of the stellar atmosphere. The asymmetric winds from the dying stars start to sculpt their circumstellar envelopes. The dust around the core that prevented the light from escaping outward has disappeared and energetic rays and fast stellar winds interact with the escaping atmosphere. A fast stellar wind of gas, which is energized by light pressure from the hot core, blows off the outer layers of the central star creating an elongated shell of dense, glowing gas. This elongated shell is known as planetary nebula.

Planetary nebulae are an expanding shell of gas ejected from a star during the latter stages of its evolution. The name planetary nebula comes from the similarity between how planetary nebulae look like the planet Uranus with a greenish-blue disk. They are composed of ionized gases like nitrogen and oxygen. Planetary nebulae are bright in the visible, radio,
infrared, ultra-violent and x-ray sources, yet, their brightness in the radio sources will decrease as a planetary nebula's ages and expands as well as become more diffuse. They have radii in the range of 0.2 to 3 light-years and an expansion rate of 10 to 20 km/s. The youngest planetary nebulae are bright as radio sources while full-grown planetary nebulae, which are made of glowing plasma, are ionized by ultraviolet light from the central star. Calculation of ages based on the expansion rate shows that planetary nebulae are in most cases no more than 10,000 years old. Researchers have identified about 1500 planetary nebulae thus far. The older planetary nebulae have combined with the interstellar medium and are not detectable.

Planetary nebulae display paired lobes, jets, hourglass shaped shells, or other bipolar forms that will appear nearly circular, elongated, dumbbell figure or opposing lobes. These peculiar shapes are believed to be the result of a star or planet orbiting the central star, rapid rotation or magnetic fields. Researchers have three theories about how the shapes of planetary nebulae are formed.

The first theory states that strong magnetic fields helped shape the star's stellar winds, which shape the planetary nebula. Strong magnetic fields are associated with fast rotation that could shape planetary nebulae but giant stars are mostly slow rotators. This means that a central star's stellar winds would not be fast enough to create the shapes.

The second theory states that the central star has a binary (orbiting) companion that shapes the out flowing gas known as planetary nebula. A binary companion could be possible and if so, it might be responsible for a pair of high speed jets of gas that lie at right angles to the equatorial ring. This means that the binary companion was attracting materials from a nearby star and jets of gas were escaping off of the binary companion’s rotation axis causing gas lobes. The jets would explain several puzzling features along the outside edge of the gas lobes. However, the twin jets are pointing in different directions than suggested by several features that were
observed. This could only mean that the jets are wobbling and turning on and off episodically. Nonetheless, the shape of the planetary nebula is not a geometric concept but a result of the physical processes that are constantly occurring in the nebula. Nevertheless, researchers lean toward the second theory, even though, there are certain events that can occur to make a giant star spin fast enough so the first theory could possibly be right.

The third theory is that the unseen, high-density, neutral materials around the core confine the central torus and force an outflow of materials from the star. This outflow escapes through the torus creating bipolar lobes as well as shaping planetary nebulae.

Planetary nebulae also have a series of rings and extended halos. The series of rings is the result of the central star blowing off its outer layers every so many thousands of years. These rings are apart of the planetary nebulae and are composed of gases ejected during active phases of the star's evolution prior to nebula's illumination by the central star. The planetary nebula's bright inner parts are several magnitudes brighter than the extended (outer) halo, which appears as a diffuse glow and is the remnant of the envelope ejected when a star was a red giant. The glow gives the halo the name AGB halo because it is a representation of the mass loss as the star is moving along the AGB region and has not thrown off its outer layers. The halo is the first ejection from the star as it goes into its red giant stage. The AGB halo will be reclassified as a recombination halo as it becomes an expanded, cooling planetary shell. The glow of the halo will start at the deep red wavelength of the hydrogen-alpha emission line and then work its way to the blue-green of the oxygen-III line where it is going from the outer to the inner part of the nebula. The halo is a circular, bipolar filamentary structure that looks clumpy with broken arcs. On the average, a halo is two or three times the diameter of a planetary nebula.

NGC 6543

On February 15, 1786, William Herschel discovered a planetary nebula now called NGC
NGC 6543 is an abbreviation for “New General Catalog”. The NGC catalog is a book of
classified entries of deep sky objects and NGC 6543 is the 6,543 rd entry. NGC 6543 is also
known as The Cat's Eye nebula because of its series of gas loops that resemblance a cat’s eye.
NGC 6543 was the first planetary nebula to be spectroscopically investigated and it displayed a
peculiar emission line spectrum. English amateur astronomer William Huggins gathered this data
in 1864. The emission lines were small in numbers with the brightest of them being 500.7
nanometers, which did not correspond to any known element at the time. Later it was discovered
that the emission line at 500.7 nanometers was the familiar element oxygen, which has been
doubly ionized and is being observed in low-density conditions.

NGC 6543 surprisingly revealed intricate structures of concentric gas shells with jets of
high-speed gas and unusual shock-induced knots of gas as viewed with NASA's Hubble Space
Telescope. Modern telescopes show a figure of NGC 6543 as transparent hourglasses or barrels
tipped at various angles creating a display with two-sided symmetry. Beside the discovery of a
glowing bubble of hot gas, scientists noticed an unexpected X-ray bright central star, which is an
O-type star, within the structure of the planetary nebula.

NGC 6543 is 8 th magnitude and located almost exactly in the direction of the North
Ecliptic Pole. This means that the normal vector of Earth’s orbital plane points to a direction
very close to the planetary nebula NGC 6543. NGC 6543 can be found in the northern
constellation Draco, which lies midway between Delta and Zeta Dra. NGC 6543 is about 3000
light years from Earth. It has a diameter of 20 arc seconds and an extended halo of matter that is
386 arc seconds. This means that NGC 6543 is 18” wide and the outer halo is 4’ wide. The
brightest part of the Cat's Eye Nebula is about a half light-year wide where it lies in a large part
of the oldest halo from the central star. The intricate web of nebulosity of NGC 6543 is about
1,000 years old.
The outer layers of NGC 6543 are possibly outer polar caps and other debris that were created by an even earlier bursting of the central star. The materials are moving away at a speed of about 4 million miles per hour. The materials are embedded inside two larger lobes of gas that were blown off the central star in an earlier phase. The lobes are pinched by a ring of denser gas, which many scientists believe was ejected along the orbital plane of a binary companion.

NGC 6543 is one of the brightest objects of its type and has a visual record of the dynamics and late evolution of a dying star. NGC 6543 has nine faint, regular spaced rings that indicate that a bubble of gas is ejected every 1,500 years. The outer filaments are about 60,000 years old. The dust cloud around the central star weighs around 1.17 solar masses. The central star has a surface temperature of about 60,000 degrees, but the X-ray emission from the central star has a temperature of a few million degrees.

**INTERSTELLAR MEDIUM**

A planetary nebula expands at a few kilometers per second, and it will eventually become so far away from the central star that its ultraviolet radiation will no longer ionize it. The gas clouds will become invisible and gradually disperse into the interstellar medium (ISM). The gases of planetary nebulae contain a large proportion of elements such as carbon, nitrogen, and oxygen. These elements are mixed in with the interstellar medium and provide heavy elements to the next generation of stars and planets.

The ISM is the gas and dust distributed between the stars. The gas, which is 99 percent of the ISM, can be hot or cold and the dust, which is 1 percent of the ISM, can be small or large because the interstellar medium is not uniform. Actually, the interstellar medium is very clumpy and the different clumps are the result of the differences in temperature and density of its four components. The components are HI clouds, intercloud medium, coronal gas and molecular clouds.
The HI clouds are not ionized but are neutral gases. They are very cool with temperatures that range from 50 to 150 Kelvin and densities of about ten to a few hundred atoms per cubic centimeters. They are long, twisted filaments that are flatten into thin sheets or tangled into chaotic shapes.

Within these HI clouds, a hot intercloud medium lies and is made up of ionized hydrogen with the gases ionized by the ultraviolet photons in the starlight. Its temperature is about a few thousand Kelvin and densities of 0.01 atoms per cubic centimeters. The intercloud medium is in equilibrium with the HI clouds because its hot, low-density gas has about the same pressure as the HI clouds’ colder, denser gas.

Molecular clouds are very dense and located inside the densest clouds where dust absorbs and scatters the short-wavelength radiation because its molecules are very fragile and a high-energy photons in the ultraviolet would break the molecules into separate atoms. The molecules emit energy as radio and infrared photons that escape from the clouds keeping the interior of the clouds very cool through molecular radiation. These clouds can be as large as 60 pc in diameter with a mass up to a million solar masses. Within these molecular clouds, stars are born and the energy from these hot stars and supernova explosions create coronal gases.

X-ray telescopes have detected x-rays with extremely high temperatures in some regions of the interstellar medium. These regions are filled with coronal gases that have a temperature of about a million Kelvin and higher and densities of 0.0004 to 0.003 atoms per cubic centimeters. Coronal gas is the extremely high-temperature, low-density gas in the interstellar medium. Neighboring shells of coronal gases often form to produce an even larger volume of coronal gases. Astronomers believe that coronal gases account for only 5 percent of the interstellar mass while the approximate amounts for other regions include HI clouds at 25 percent, intercloud medium at 50 percent, and molecular clouds at 25 percent. Studies of the interstellar absorption
lines reiterate the composition of gases in the interstellar medium. They indicate that hydrogen is
the most abundant but helium, nitrogen, oxygen, carbon, iron, calcium, and titanium are also
among the gases present.

Iron, calcium, and titanium condense to form the dust in the ISM. Dust has two major
effects on light passing through it. First, the dust dims the light, which is interstellar extinction.
Secondly, interstellar reddening can occur because the transmitted light will be redder and
reflected light will be bluer. The interstellar medium is invisible to the naked eye so it is
observed at wavelengths of infrared, radio, and the shorter wavelengths of ultraviolet and X-ray
radiation. The total mass of the gas and dust in the interstellar medium is about fifteen percent of
the total mass of visible matter in the Milky Way.

Interstellar dust grains are typically a fraction of a micron across, irregularly shaped, and
composed of carbon or silicates. Absorption of light by dust causes large dark regions in our
galaxy. Dust clouds are visible if they absorb the light coming through them, which would make
the clouds dark nebulae. However, if the light reflects from the clouds of dust and gas, reflection
nebulae are formed.

There are three kinds of nebulae, which are emission, reflection, and dark. The
differences between these nebulae give scientists a better understanding about our interstellar
medium.

Emission nebulae are produced when a hot star excites the gas near it to produce an
emission spectrum. Emission nebulae have a signature pink color that is produced by the
blending of the red, blue, and ultra violet Balmer lines.

A reflection nebula is produced when starlight scatters from a dusty nebula. When this
happens, the absorption spectrum of the star is reflected. While gas is surrounding the star, it
does not get excited and emit photons.
Dark nebulae are dense clouds of gas and dust that obstruct our view of more distant stars. Dark nebulae are responsible for holes and rifts along the interstellar medium.

**ATOMIC PROCESSES IN THE PLANETARY NEBULAE**

The Cat's Eye Nebula's images we studied were taken with two Sulfur II narrow-band filters, 6717 and 6731. The singly ionized sulfur ion emits photons that are transmitted through the filter. The photons that hit the filter were a result of several atomic processes in the nebula. These atomic processes of importance to our study are ionization, collisional excitation, and spontaneous deexcitation, which aid in the production of photons.

Inside the core of a white dwarf star, ultra-violent photons are created and emitted into the surrounding nebular gases. These gases then become ionized during the first atomic process ionization. Ionization occurs when atoms in the gases absorb energetic photons and an electron is stripped away from the atom or ion.

There are free electrons moving around among the S$^+$ ions inside the gases. When a free electron hits an S$^+$ ion, the free electron transfers some of its kinetic energy to the S$^+$ ion. The S$^+$ ion suddenly moves to a more energetic state. This is the second atomic process mentioned above called collisional excitation. Collisional excitation occurs when a free electron collides with an ion.

The third and final step is one in which the S$^+$ ion spontaneously decays to the ground state and a photon is released, spontaneous deexcitation has occurred. Spontaneous deexcitation is the release of a photon from a S$^+$ ion when a bound electron jumps to a lower energy state. This photon then travels to the charged coupled device (CCD) chip landing on one or more of the pixels.

**DATA SET & ANALYSIS**

Our images of NGC 6543 were taken with the 1.3 meter Robotically Controlled
Telescope at Kitt Peak National Observatory. The telescope took images of NGC 6543 with two sulfur II filters, 6717 and 6731. The sulfur II 6717 had a central wavelength (CWL) of 671.6 nanometers and a full width half maximum (FWHM) of 0.9 nanometers meaning that photons with wavelengths 0.45 nanometers above or below the central wavelength pass through the filter but most other wavelengths are blocked. The sulfur II 6731 has a CWL of 672.9 nanometers and a FWHM of 0.8 nanometers.

CCD camera on the telescope acquired our images. CCDs have revolutionized the way astronomers and other researchers obtain images of celestial objects. CCDs are very effective, however, they are prone to saturation, cosmic ray hits, bad pixels, et cetera. A properly calibrated digital image has to have its noise sources minimized. Therefore, image processing is used to transform the raw images of the “Cat's Eye” nebula into useful images using the Image Reduction Analysis Facility (IRAF) software package, which is logged onto through an x-terminal window in LINUX.

IRAF is a software package that uses commands to carry out astronomical image processing. The processing of NGC 6543 data requires the use of many IRAF commands. These commands aid in the tedious process that it takes to clean up the bias, flat, and object frames with speed and accuracy. The commands we used are listed in the following table.

<table>
<thead>
<tr>
<th>COMMAND</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>chpixtype</td>
<td>change the pixel type of a list of images</td>
</tr>
<tr>
<td>imarith</td>
<td>simple image arithmetic</td>
</tr>
<tr>
<td>imcopy</td>
<td>copy an image</td>
</tr>
<tr>
<td>imdelete</td>
<td>delete a list of images</td>
</tr>
<tr>
<td>imheader</td>
<td>print an image header</td>
</tr>
<tr>
<td>imhistogram</td>
<td>compute and plot or print an image histogram</td>
</tr>
<tr>
<td><strong>COMMAND</strong></td>
<td><strong>FUNCTION</strong></td>
</tr>
<tr>
<td>---------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>imrename</td>
<td>rename one or more images</td>
</tr>
<tr>
<td>imreplace</td>
<td>replace a range of pixel values with a constant</td>
</tr>
<tr>
<td>imsum</td>
<td>compute the sum, average, or median of a set of images</td>
</tr>
<tr>
<td>imstatistics</td>
<td>compute and print statistics for a list of pixels</td>
</tr>
<tr>
<td>listpixels</td>
<td>convert an image section into a list of pixels</td>
</tr>
<tr>
<td>minmax</td>
<td>compute the minimum and maximum pixel values in an image</td>
</tr>
<tr>
<td>display</td>
<td>load an image or image section into the display</td>
</tr>
<tr>
<td>imred</td>
<td>image reductions package</td>
</tr>
<tr>
<td>crutil</td>
<td>package of tasks for detecting and removing cosmic rays</td>
</tr>
<tr>
<td>imalign</td>
<td>register a list of images by computing relative object shifts</td>
</tr>
<tr>
<td>crcombine</td>
<td>combine multiple exposures to eliminate cosmic rays</td>
</tr>
<tr>
<td>fixpix</td>
<td>fix bad pixels by linear interpolation from nearby pixels</td>
</tr>
<tr>
<td>cosmicrays</td>
<td>remove cosmic rays using flux ratio algorithm</td>
</tr>
<tr>
<td>contour</td>
<td>make a contour plot of an image</td>
</tr>
<tr>
<td>temden</td>
<td>task that calculate sulfur density using 6717 divided by 6731</td>
</tr>
</tbody>
</table>

The table is a list of commands that are used to remove the noise sources from the bias, flat, dark, and object frames as well as further process the images. These frames are initially raw images captured by the telescope. Each frame contributes certain noise sources, which must be removed or corrected.

Bias frame is an image that has an exposure time of zero. It contains the readout noise from the amplifier and the camera's electronics. Figure 1 is a picture of the bias frame.

Dark frame is an image that shows thermal noise from the CCD's chip for an accumulated exposure time. An example of the thermal noise is pictured in Figure 2.

Flat frame is an image of a uniform field of light. It shows the sensitivity variations of the
pixels in the CCD as well as dust particles that sit on the CCD's cover as shown in Figure 3.

Figure 4 shows an image of the planetary nebula NGC 6543 and surrounding stars. This is called the object frame and contains noise from the bias, dark, and flat frames.

The imaging process begins with the renaming of the original file names. This is important because the imaging processes that will take place later will need a symbol or a letter as representation of what was performed on the image at each step. Therefore as progression occurs in the steps of image processing, each step will have an identifiable symbol or letter just in case backtracking to a particular step is needed.

As each step is being performed, it is helpful to constantly look at the images in a ds9 window. DS9 is a window created by Smithsonian Astrophysical Observatory at Harvard that allows images to be viewed in three viewing windows. There is one large window called the main viewing window that allows an image to be displayed. In this window, the cursor can be moved around by the mouse or manually with cursor keys and with each movement; the pixel value (x, y) is shown. In the two smaller windows, one called the “pan” window shows an outlined of the image and allows the user to quickly move the main viewing window around the image. The third is the “zoom” window and it shows a high magnification of the area where the cursor is positioned. DS9 aids in the viewing of the noise sources in an image and their location. It has many button controls, like zoom, scale, color, et cetera that will assist in making the image viewed as perfect as possible. In the ds9 window, multiple images can be seen at one time or blinked making several images easily comparable.

One can use imstat and imhist to also compare image statistics for a single image or a group of images. Imstat gives the statistics of an image such as minimum and maximum value, mean, standard deviation, et cetera while imhist gives the histogram of the image. These two commands are used constantly throughout the image processing.
There are important changes to the images that are needed to be made.

<table>
<thead>
<tr>
<th><strong>STEP</strong></th>
<th><strong>PREFIX</strong></th>
<th><strong>NAME</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>original image</td>
<td>none</td>
<td>3182-obsG-1.fits</td>
</tr>
<tr>
<td>rename file</td>
<td>none</td>
<td>s17.1.fits</td>
</tr>
<tr>
<td>trim image</td>
<td>t</td>
<td>ts17.1.fits</td>
</tr>
<tr>
<td>bias subtract</td>
<td>bs</td>
<td>bsts17.1.fits</td>
</tr>
<tr>
<td>flat field</td>
<td>ff</td>
<td>ffbsts17.1.fits</td>
</tr>
<tr>
<td>allignment</td>
<td>a</td>
<td>affbsts17.1.fits</td>
</tr>
<tr>
<td>imsum</td>
<td>none</td>
<td>sum17.fits</td>
</tr>
<tr>
<td>ratio</td>
<td>none</td>
<td>ratio17_31.fits</td>
</tr>
</tbody>
</table>

One of the changes is converting all the images' pixel values to real from ushort. In order to perform this task, chpixtype is used. Chpixtype has a way of changing all of the image's pixel values at one time instead of performing this task individually. Nonetheless, it is important for the pixel value to be real for the future use of the data. Another important change is trimming the images. Each image has bias overscanned columns located on the edges of the images. Using imcopy, the name of the image, and the x and y dimensions we want to remove, the images are trimmed. The x and y dimensions of the image must be identical because the image should have a shape of a square. Imhead is then used to show the dimensions of the image. The naming of the image so it symbolizes that trimming has been done is recommended.

The next area of focus is to remove some of the cosmic rays and average the bias images. These two steps can be performed at the same time using the command crcombine. Crcombine will remove as many cosmic rays and average the three bias frames at once creating an average bias frame with cosmic rays removed. In order for crcombine to perform this task its parameter must be set properly. After the average bias is created, it will be used to remove the bias frames from the trimmed flat and object frames. This step will be performed with the use of imarith.
Imarith is a command that allows an image or number to be added, subtracted, multiplied, or divided by some image or number. The bias average will be subtracted from each trimmed flat and object frames creating new bias subtracted flat and object frames. The naming of the images to symbolize bias subtracted is important if needed to back track.

Crcombine will once again be used to average three frames. This time the three flat frames with the same second exposure time will be averaged using the same parameter used in the averaging of the three bias frames. An imstat will be done on the average flat frame in order to get its mean value. Imarith will be used to divide the mean of the average flat into the average flat image creating a normalized average flat. If these steps are done correctly, the mean of the normalized average flat will be one. Now it is time to flat field the object frames. In order to create these flat-fielded images for the objects, imarith is used to divide the normalized average flat into each of the three object frames creating three flat-fielded object images. The naming of the images to symbolize flat fielded is a wise decision.

Imalign is a command that takes several images that are alike, which means that they have been taken with the same camera, exposure time, and of the same object, and align them so that each location in space is at the same pixel position in all images, and would fit perfectly on top of one another. The three object images will be aligned using the image coordinates of several stars as reference points in one of the images to align the other two object images. Imalign also trimmed the three images so that each object image has the same dimensions. DS9 window will be used to gather the image coordinate of the stars and later to make sure the three object images are aligned. If the images are not aligned, they will not overlap properly thus looking like Figure 5A. If they are aligned correctly, the resultant images will look like Figure 5B. Imhead will be used to display the three object images' dimensions. The naming of the aligned images is very important so that they are kept separately from the unaligned images.
Alignment of the object images improves appearance of the object image but there are still other things that are needed to be done to the images. The images normally have bad columns that are needed to be removed. Fixpix is a command used to remove these bad columns by using the ds9 window to identify the location of the bad columns. A text file is created with the bad columns' coordinates and is used in the fixpix. The naming of these bad columns removed object images are needed.

Looking at the object images in ds9, cosmic rays are still visible and need to be removed. Therefore, a second cosmic rays removal is needed. This time, a command called cosmic rays was used to eliminate a few more cosmic rays, however, a “ghost” of some of the cosmic rays will remain. Figures 6A and 6B show an example of the raw image and the final cleaned image.

Now the almost perfect object images are ready to be added together and summed creating one object image. Imsum is a command used to do the summing of the three object images. Its parameters must be correctly set in order for it to work properly. Now that there is only one image (Figure 7A & 7B), it is time to do a sulfur ratio map. This map is created by using two summed object images, which came from different filters but are of the same object and exposure time, and aligned the two images using imalign. Once the alignment is complete and a success, imarith is used to divide the two images, 6717 into 6731, creating a sulfur ratio map (Figure 8A & 8B).

To show our sulfur ratio map, we used the display command, which is located in the tv package. The display command gave us control over the scaling of the image. This was important because the ds9 window displayed the entire range of values, therefore, the nebula would not appear unless we manually set the scale.

In order to show more details inside NGC 6543, a contour map is overlaid onto the sulfur ratio map (Figure 9). This contour map will assist in showing the structures of the nebula as a
function to the different densities.

Using the pixel values inside the nebula from the ratio map, the density is calculated. The command temden allows the pixel value to be entered and it outputs the density if its parameters are correctly set to output the density.

Imreplace, an iraf command, is used to replace the pixel value with the density. A density map (Figure 10) is created to show the number of electrons per cubic centimeters of a given pixel. To see the steepness of the density areas, a contour map is placed on top of the density map (Figure 11).

RESULTS & FUTURE WORK

We are planning on comparing our result to the previous research published in the literature. Our results will then be ready to be compared to the modeling results of other. Additionally, we will present these preliminary results at a future student research conference.

Figure 11 and 12 are preliminary density calibration images. There are four high density regions in both figures. The large left lobe contains the highest concentration and has the steepest gradient. The upper right lobe has a higher density and a steeper gradient than the lower right lobe. The results in the center are not very accurate due to the presence of a star. Therefore, the concentration that you see in the center comes from both the central star and the gas surrounding it. To make our results more accurate we would have to remove the values that come from the star. The other parts of the nebula have low and nonuniform densities. If you refer to Figure 12, you would observe that the gray areas are clumped in certain places, and that the distribution of electrons is not uniform. The low density regions are either white or a light gray.

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Figure 1. Bias Frame

Figure 2. Dark Frame

Figure 3. Flat Frame
Figure 4. Object Frame

Figure 5. [A]

Figure 5. [B]
Figure 6. [A] before cosmic ray removal  
Figure 6. [B] after cosmic ray removal

Figure 7. [A] Sulphur 6717  
Figure 7. [B] grey scale

Figure 8. [A] Sulphur 6731  
Figure 8. [B] grey scale
Figure 9. [A] ratio map of NGC 6543
color scale

Figure 9. [B] ratio map of NGC 6543
inverted grey scale

Figure 10. ratio map of NGC 6543
with contours
Figure 11. density map in color

**SCALE**
YELLOW- greater than 1500 electrons/cm$^3$
ORANGE- 1300-1500 electrons/cm$^3$
RED- 1150-1300 electrons/cm$^3$
PINK- 900-1150 electrons/cm$^3$
PURPLE- less than 900 electrons/cm$^3$

Figure 12. density map of NGC 6543
inverted grey scale with contours

**SCALE**
BLACK- greater than 2000 electrons/cm$^3$
GREY- 600-2000 electrons/cm$^3$
WHITE- less than 600 electrons/cm$^3$