ASTRO 1050 - Fall 2012
LAB #10: Stellar Evolution and Planetary Nebulae

ABSTRACT

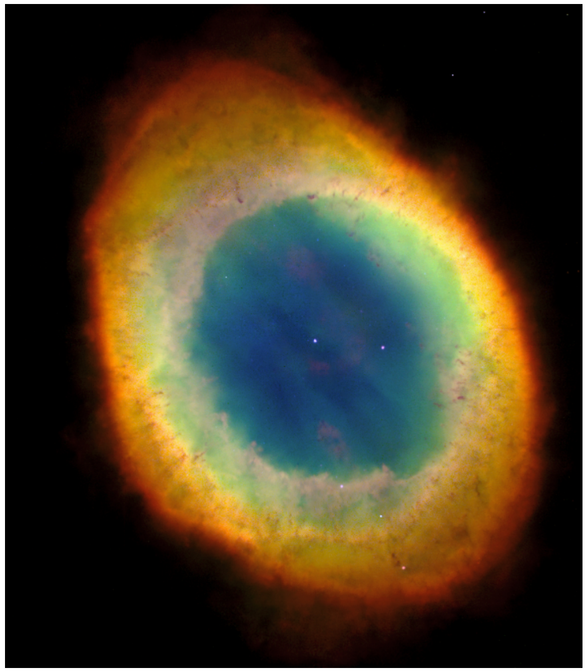
All stars form when giant clouds of gas and dust collapse due to their mutual gravity. Over the course of millions of years, these pro to-stellar clouds compress until they ignite nuclear fusion in their cores. This is how stars create energy throughout the majority of their lifetimes. Depending on the mass of the star, this timespan may range from only a few million years for the most massive stars to trillions of years for the least massive (much older than the age of the Universe!). But how do stars die? Will its core collapse to form a dense white dwarf as the outer layers are expelled as a planetary nebula? Or will the star explore in a supernova that collapses into an incredibly dense neutron star or black hole? In this lab we will study low mass stars and their corresponding stellar remnants: planetary nebulae. You will use multiple images of the Ring Nebula taken at different wavelengths. This will allow us to estimate how much mass was ejected and how long that process takes.

1. Planetary Nebulae

The term for these stellar objects is a partial misnomer. When William Herschel first viewed a planetary nebula through his telescope, he thought they looked like clouds (nebulae) that were similar in appearance to Uranus. While planetary nebulae do consist of stars, they do not consist of planets. Please, do remember this! **Planetary Nebulae ≠ Planets**!

A planetary nebula consists of an expanding glowing shell of ionized gas that is ejected during the death of a star. At the end of the star's life, the outer layers of the star are expelled through several pulsations and strong stellar winds. Without these opaque layers, the hot, luminous core emits ultraviolet radiation that ionizes the recently ejected layers of the star. This shell then radiates as a planetary nebula. Eventually the central star becomes a white dwarf, and its luminosity falls by as much at 90%. The star is no longer capable of ionizing the nebula, leaving it to gradually fade and disperse into the interstellar medium.

But how do we know this? We can't simply watch the entire process (we will learn later that it takes far too long). We can, however, observe different planetary nebulae at different stages. We can also observe a single planetary nebula in different wavelengths. Remember



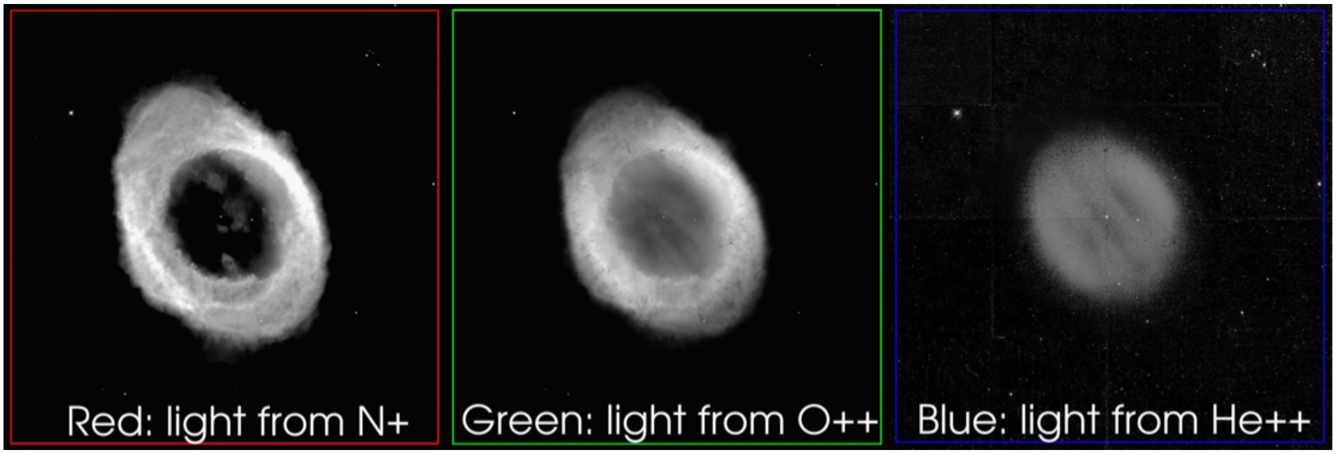
that different atoms and molecules show a different pattern of spectral lines. Thus if we look at an image at different wavelengths we can determine the present atoms or molecules.

Planetary nebulae play a crucial role in the chemical evolution of our galaxy. They return material to the interstellar medium that is composed of heavier elements. The Big Bang produced 75% Hydrogen and 25% Helium. All other elements have been formed later in the central regions of stars. These are the products of nucleosynthesis (such as carbon, nitrogen, oxygen, and calcium). Recognize these elements? They are crucial to life as we know it.

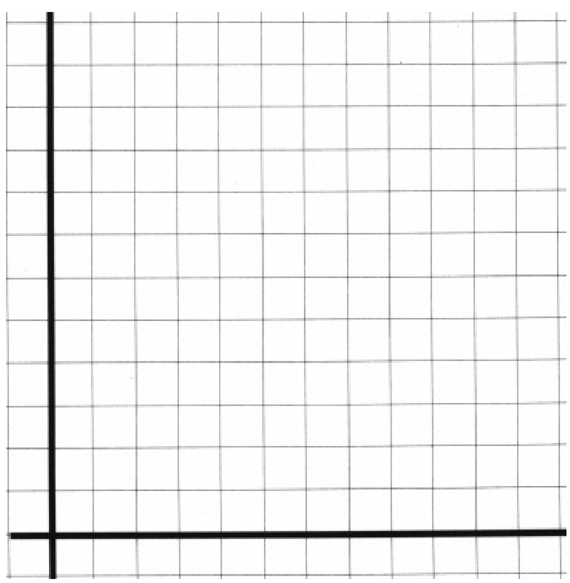
2. The Ring Nebula

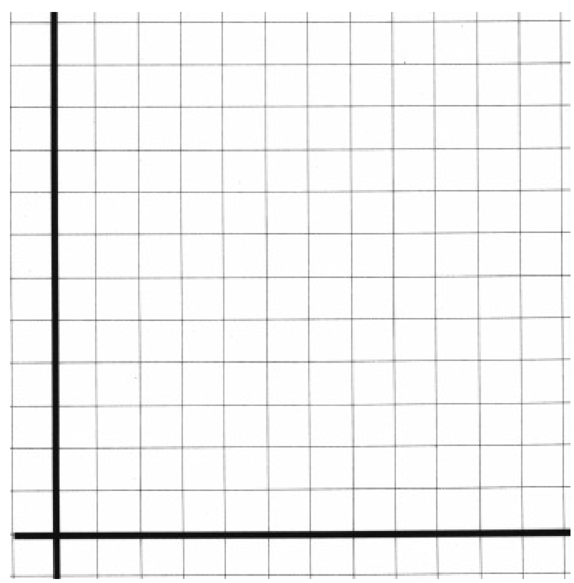
One of my favorite objects to observe in the deep night sky is the Ring Nebula. While the image above is vastly colorful, with each color revealing the temperature of the gas, when observing the ring nebula through a telescope it appears to be a 'small cheerio in the sky.' One of our goals today is to determine exactly how large a cosmic bowl of milk will have to be in order to hold this one cheerio.

Examine the images of the Ring Nebula below. The brighter regions of the images are areas where the density of the nebula is high. This is because there is more material to create emission in these regions.



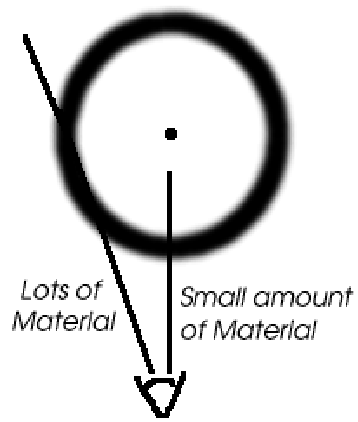
Using the O++ image, make a plot of the mass loss versus time. Plot the brightness of the nebula on the y-axis, and the distance on the x-axis. Label your axes with arrows indicating increasing brightness, and increasing distance. Be sure to mark the position of the central star. Do this for both the long and short axes of the nebula (not the image!)





Are the two plots similar in shape? Explain!

One way to interpret these data is to guess that the nebula is actually a hollow sphere. Then the middle is dim because there is less material along the line of sight, while the outer shell of the nebula is bright because you are looking through the material at the outer edge.



3. The Size and Age of the Ring Nebula

- Estimate the length of the long axis of the nebula in the O++ image. The total height of the image is 400 arcseconds.

- We would like to determine the physical radius of the Ring Nebula, R, based on the radius it subtends on the sky, α (given in arcseconds, a fraction of a degree), as well as its distance, D, from Earth. Recall trigonometry and draw a picture below!

Using this triangle on the sky, one may use the small angle formula to determine the physical radius of the Ring Nebula. Does your above schematic prove this? If not, ask me a good question! Note that the number 206,265 is a conversion factor between arcseconds and degrees. This allows α to be in arcseconds.

$$R = \frac{D\alpha}{206265} \tag{1}$$

- The distance, D, to the Ring Nebula is 3.4 x 10^{16} km. What is the physical radius? In other words: how large would the cosmic bowl of milk need to be in order to hold the cheerio? Show your work and state your units!!

- To understand more clearly the size of the nebula, convert the long axis (in km) to astronomical units (1 AU = 1.5×10^8 km). For a sense of scale, the entire Solar System is approximately 80 AU across.

- We can assume that the nebula has been expanding at 20 km/s since it first began losing mass. If the gas has been blowing outward from the central star at a constant rate, we can determine the time that this has taken. In order words you can determine the age of the Ring Nebula! Don't forget to convert the age into units that give you a sensible answer!

- Place the age of the Ring Nebula in context. Is it greater than the span of human history? Where is it in a cosmological context? Do a little research...

4. Mass Return Rate

We would now like to understand how much mass has been lost throughout this process. The volume of a sphere is:

$$V = \frac{4}{3}\pi R^3. \tag{2}$$

- Use this formula (with R in km) to find the volume for the inner part:

- And the outer part:

- Subtract the two to find the volume that emits light:

- The density of the this volume is very low, n = 1.7 x 10^{-10} kg/km^3. Multiply this density by the volume to get the mass in the Ring Nebula in kilograms.

- To understand more clearly the mass of the nebula, convert this mass to solar mass ($M_\odot$). The mass of the Sun is 2 x 10^{30} kg.

- If the original star had a mass of one solar mass, what fraction of its mass did it eject into the nebula?

- The entire mass of this nebula will become a part of the interstellar medium. There are about 700 planetary nebulae in our galaxy. Estimate the mass returned to the interstellar medium each year by multiplying the mass of the Ring Nebula by the number of nebulae, and dividing by the lifetime of the Ring Nebula (in years).

- New stars form at the rate of about one solar mass per year. Can planetary nebulae be solely response for producing the gas which is made into these new stars? (Explain your reasoning).