LAB #12 - Planetary Nebula

*This lab is to be completed in groups of 2-3 and you should all participate actively. You should answer all of the questions and hand in **just one copy per group** with all your names on it. However, it is to your advantage if you all keep a record of your answers so you will have something to study from.*

Purpose:

- gain an appreciation for the sizes and timescales involved in the planetary nebula phase of stellar evolution.
- estimate how much mass is returned to the interstellar medium by planetary nebula every year.
- investigate the processes behind nebular emission.

Materials:

- Ruler
- Internet access

Introduction:

Many low-mass stars eject their outer layers before becoming white dwarfs. The result is the formation of a "Planetary Nebula", such as the Ring Nebula in figure 1. You will use an image of the Ring Nebula to estimate how much mass is ejected, and how long the process takes. You will also explore whether planetary nebulae replenish the interstellar dust and gas significantly.

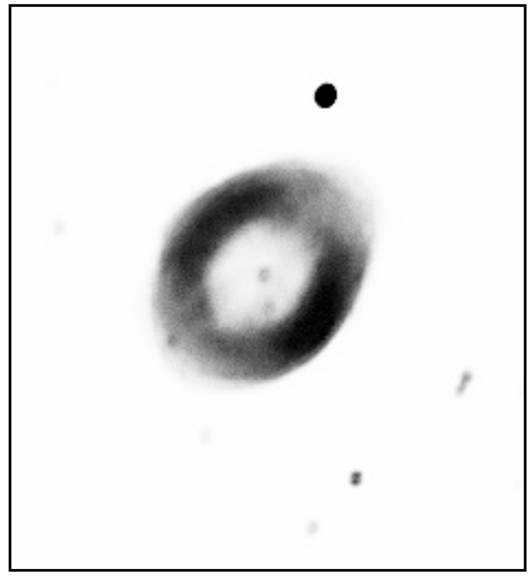
Background:

A planetary nebula is formed when a red giant star approaches the end of its life span and begins to lose a lot of mass very quickly. This mass condenses and forms an expanding shell around the star. The hotter, ultraviolet emitting layers of the star ionize the gas in the nebula. This ionized gas begins to glow, making the nebula luminous.

Eventually, the central star becomes a white dwarf, and its luminosity falls by as much as 90%. The star is no longer capable of ionizing the nebula, so the nebula gradually fades and disperses into the interstellar medium.

Adapted from University of Washington astronomy clearinghouse lab

Section A. Geometry of the Nebula and Mass Loss History

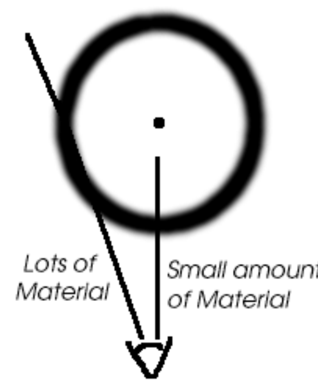


1. Examine the image of the Ring Nebula on the right, which is close to what you would see if you observed it through a small amateur telescope (in this image, the grayscale has been inverted, so that darker regions are brighter, and the background sky is white). Material closer to the central star was probably lost more recently, while material far from the star was probably lost longer ago.

   Using this image, we will make a plot of mass loss versus time. First, plot the brightness of the nebula vs distance along the long axis. Label your axes with arrows indicating increasing brightness, and increasing distance. Be sure to mark the position of the central star.

2. Make the same sort of plot for the short axis. Are the two plots similar in shape?

3. One way to interpret these data are 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 all around the outside, the nebula is bright where you are looking through the material at the edge of the bubble. How do your observations differ from this model? How are they consistent?



4. Now make a sketch of the mass loss history of the star, using the fact that material which is more distant from the central star was shed in the more distant past. This time, your plot will have time on the x-axis, and mass loss on the y-axis.

5. Has the mass loss been constant over time? Describe the history of the mass loss from the central star.

Section B: Size and Age of the Ring Nebula

1. Estimate the angular size of the long axis of the nebula in arcseconds if the total image height is 2 arcminutes. [Remember that 1arcminute=60 arcseconds, and 1 degree = 60 arcminutes].

2. Now, find the actual radius, R, of the nebula using the small angle formula:

$$\frac{R}{D} = \frac{\theta}{57.3}$$

which relates the angular size of an object on the sky to its distance from the observer. You can assume the distance, D, to the Ring Nebula is 2.2×10^{16} km (or 2,300 light years) and θ is in degrees. Make sure to show your work and include a unit in your answer.

3. Astronomers have measured the speed of the expanding nebula to be a speedy 20 km/s. Given this speed, and the size of the nebula which you just found, find the age of the Ring Nebula, i.e. how long ago did this star start shedding its outer layers?

4. Put these numbers in perspective by dividing the length of the nebula (in km) by the distance from the Earth to the Sun (1AU = 1.5×10^8 km). If the entire Solar System is about 80 AU across, how many times bigger is the Ring Nebula than the solar system?

Section C: Mass Return Rate

1. Use the formula for the volume of a sphere: $V=(4/3)\,\pi\,R^3$ to find the volume inside the Ring Nebula. Use the same formula to find the volume of the hollow inner part. (You will need to find the radius of this inner part, as in steps B1-B2).

2. Subtract the inner volume from the outer volume to find the volume that emits light.

3. The density of the nebula is very low, $n=1.7 \times 10^{-10}$ kg/km^3. Multiply this density by the volume to get the mass in the ring in kilograms.

4. If the original star had the same mass as the sun (2×10^{30} kg), what fraction of its mass did it eject into the nebula?

5. Stars die and form planetary nebula in our galaxy at a rate of about 1 per year. However, as you'll see later in the course, the galaxy is also forming new stars, at the rate of about 1 solar mass per year. Given the fraction of mass ejected by planetary nebula, is the amount of recycled material enough to fuel the new star formation?

Section D: The Ring Nebula in Color (... to be completed at home)

1. Go to http://heritage.stsci.edu/2013/13/big.html to see what the ring nebula looks like through the Hubble Space Telescope, this time in glorious color. Based on what you learnt in class and your own internet research, write a paragraph on why the color of the nebula in this picture changes with radius, from blue in the center to green then red in the outskirts. What two main factors determine which colors are emitted by a nebula? (Hint: think about how light is being generated in the nebula and what kind of spectrum it will emit - you can see a spectrum of the ring nebula here: http://stars.astro.illinois.edu/sow/ring-p.html).