

Calculating the Age of a Planetary Nebula

Contents

Introduction.....	1
Downloads	1
Part 1: Measuring the Size of the Planetary Nebula	2
Part 2: Calculating Age	4
Discussion and Further Work.....	5

Introduction

The object imaged by the Faulkes Telescope North for this activity was the planetary nebula (PN) commonly known as the *Ghost of Jupiter* nebula (NGC 3242). A planetary nebula is the remnant of a star about the size of our Sun. This star has fused all the material it can and has ended its life by puffing off its outer layers. This has left a shell of expanding gas (the nebula) and a slowly cooling remnant of the stellar core called a white dwarf. You can determine how long it has been since the star formed this planetary nebula by:

- measuring the angular size of the PN from the FITS image in IRIS;
- obtaining a reference value for the expansion rate of the nebula's gas;
- obtaining a reference value for the distance to the PN;
- converting angular size to physical size; and
- dividing physical size by expansion rate to calculate the length of time the shell has been expanding.

The answer may be compared with reference values to determine the accuracy of your measurements and calculations.

Downloads

From here you can download everything you need to get you started with the Planetary Nebula project.

1. Download and install IRIS

This software will allow you to view FITS files from the Faulkes Telescope and read off pixel positions from images. Follow the instructions for **Configuring IRIS** to set your working path to **C:\data**.

2. Download the image file

Save this file to your hard drive in the directory **C:\DATA**

ngc3242-r.fit is an image of the PN NGC 3242 obtained with the Faulkes Telescope North. The image was made through an R (red) filter. For use with IRIS, the filename must have the extension **.fit** (not **.fits**) and all letters should be in lower case. If you download other FITS files or obtain your own data to use with this project, you may need to rename the files accordingly.


Part 1: Measuring the Size of the Planetary Nebula

1. Open the image in IRIS

Select **File > Load...**

Click on **ngc3242-r.fit** and then **Open**

This should open the file but it will initially look all black. Click **Auto** in the **Threshold** window and you may also need to scroll down the image to see the PN (the PN is in the bottom half of

the image). You can zoom in or out on your image using the zoom buttons: 

The left one zooms in, the middle one zooms out and the right one restores the image to its original size. The PN itself looks something like Figure 1, which has the important features marked.

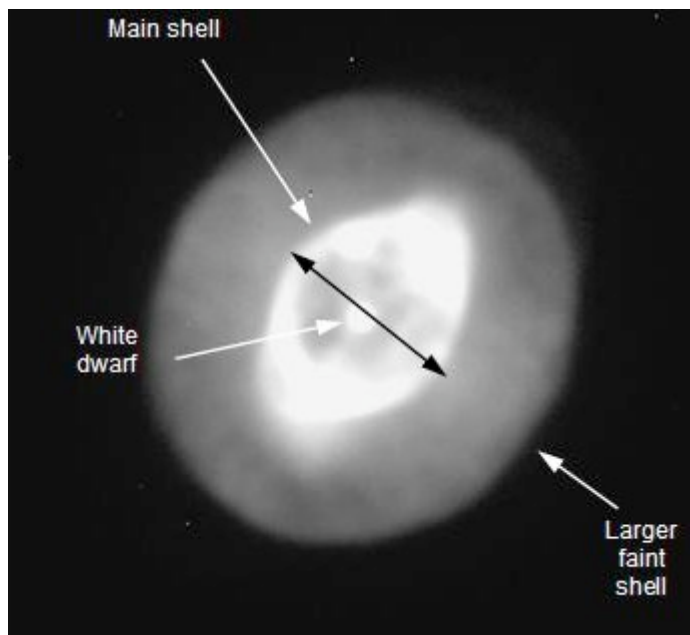


Figure 1: The planetary nebula called the *Ghost of Jupiter* (NGC 3242).

In the image you can see a bright central spot (the white dwarf) and a bright non-circular main shell surrounding the white dwarf. There is also a larger faint shell of gas visible which is probably gas that was lost by the star during its red giant phase.

2. Measure the edges of the main shell

Students must decide where they think the edge of the main shell is. There may be significant differences depending on the threshold settings each student has decided to use and this can be a topic for discussion in class: "How do you decide where the main shell finishes?"

Select **Analysis > Select Objects...**

If you get the error message **Use x1 zoom**, simply click on the **x1** button alongside the zoom buttons described above to bring the image back to the original size.

The cursor will change shape and an **Output** window will pop up on the screen. Click at one edge of the main shell and the x,y-coordinates will appear in the **Output** window. Click at the other edge of the shell and these x,y-coordinates will also appear in the **Output** window. A little + sign will show up where you have clicked. If you are not happy with your positions, you can click again. Just make sure you remember which were the correct measurements (see Figure 2).

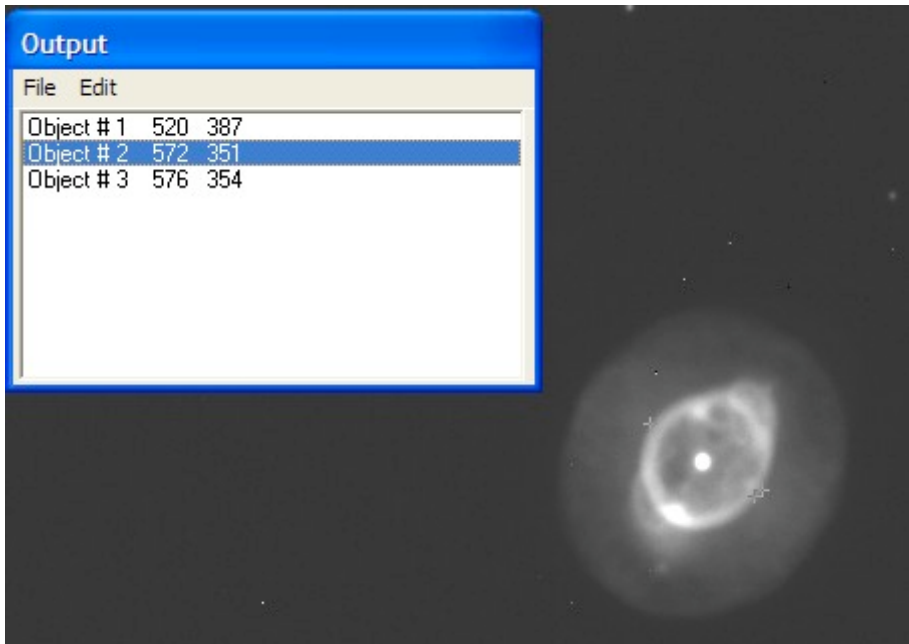


Figure 2: Measurements of the edges of the main shell of the PN in the **Output** window. The second measurement didn't look to be in a good position (not right on the edge), so #1 and #3 will be used.

3. Determine the diameter of the shell in pixels

Using the Pythagorean theorem, these x,y positions can be used to determine the apparent diameter of the shell in pixels.

$$\begin{aligned}\text{Size in pixels} &= \text{sqrt} [(520 - 576)^2 + (387 - 354)^2] \\ &= 65 \text{ pixels}\end{aligned}$$

4. Determine the angular size of the main shell in arcseconds

Each pixel of the Faulkes Telescope images corresponds to a size of 0.27837 arcseconds. This is set by the properties of the CCD camera and the focal length of the telescope.

$$\text{Size in arcsec} = 0.27837 \text{ arcsec/pixel} * 65 \text{ pixels} \approx 18 \text{ arcsec}$$

5. Find reference values for the expansion rate and the distance to the PN

For this exercise, refer to:

<http://apod.nasa.gov/apod/ap051029.html> and <http://www.blackskies.org/pnweek4.htm>

and assume:

- an expansion rate of $v = 23 \text{ km/s}$; and
- a distance of $r = 1400 \text{ light years}$.

Notes:

- There are some assumptions made at this point. This exercise assumes that the shell of gas that defines the formation of the planetary nebula is the one that is indicated in the image as the main shell. It also assumes that the expansion velocity quoted in the reference is for the shell being measured.
- These assumptions are complicated by the fact that this nebula is probably not spherical and it is hard to tell what shape it is. Many PN are shaped like an hourglass and there does appear to be some non-spherical shape in the image.

6. Determine the physical size of the PN using the small-angle formula

The appendix, taken from

<http://cosmos.phy.tufts.edu/~zirbel/laboratories/AstrometryPreLab.pdf>

explains the derivation of the small-angle formula:

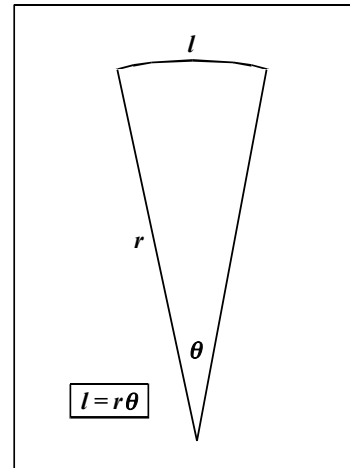
$$l = \frac{r\theta}{206265}$$

where l is the physical size, r is the distance (note that l and r must be expressed in like units – Mpc for galaxies, km for this exercise), θ is the angular size in arcseconds and 206265 is the number of arcseconds in a radian.

Note: This simplifies to: $l = r\theta$ if the angle is measured in radians. You may see this version in some references (see Figure 3).

Figure 3: Principles behind the small-angle formula. For very small angles:

- l may be considered to be a straight line (forming a right-angled triangle); and
- the tangent of an angle, where the angle is expressed in radians, is approximately equal to the angle itself.



Follow these steps to calculate the physical size of NGC 3242:

- Work out or look up how many kilometres in a light year.
- Multiply this by the assumed distance to the PN (1400 l.y.) to find r in km.
- The angle θ is the value found in Step 4 – note that this is in arcseconds.
- Plug the numbers into the correct formula to derive physical diameter l .

Your answer should be in the order of 10^{12} km.

Part 2: Calculating Age

Assuming a constant expansion rate for the PN, this formula:

$$t = \frac{l/2}{v}$$

yields the length of time the shell has been expanding (also known as dynamical age) in seconds (t), where $l/2$ is the physical radius and v is the assumed expansion velocity (23 km/s).

Follow these steps to calculate the age of NGC 3242:

- Plug your answer from Part 1 into the formula to find the age in seconds.
- Work out or look up how many seconds in a year.
- Find the age in years.

Your answer should be in the order of a thousand years.

Discussion and Further Work

1. Look up reference values for the distance to this PN.

Finding accurate distances to astronomical objects is very difficult. Estimates of the distance to this PN range between 1400 and 3000 light years. You may wish to search the internet and discuss the different values quoted.

2. Look up reference values for the age of this PN.

Compare your answer with these values and then consider these questions:

- How would the answer change if you measured the shell end-to-end instead of across the narrowest part?
- How would your calculations change if the distance was double what you have used?
- How would the answer change if you measured the large faint shell marked in Figure 1, rather than the one marked as the main shell?

3. Investigate shapes of PN.

Have a look at some other examples of PN in books or on the internet and take note of the variety in their shapes.

4. Learn more about finding distances.

Investigate how astronomers find distances to objects in our own galaxy using *annual parallax*.