The Universe in my pocket

Planetary Nebulae

TUIMP
No. 36
THE UNIVERSE IN MY POCKET

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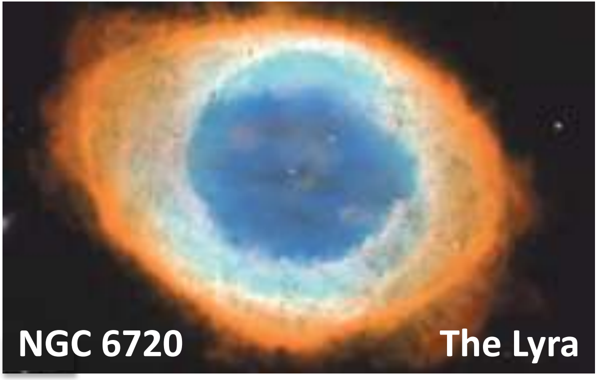


Two of the most famous planetary nebulae (Source HST)

Two famous bipolar planetary nebulae

(Source HST)

Two planetary nebulae with complex structures

A diamond ring in the sky. A spherical planetary nebula, aligned by chance with a foreground star.

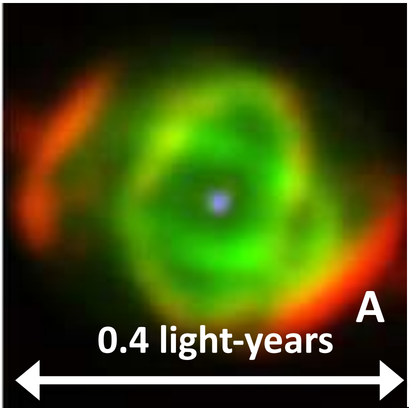
(Credit ESO)

You have certainly seen such pictures on magazines covers: These are images of perhaps the most beautiful celestial bodies.

The colours, as in many astronomical images, are actually ‘false colours’ that help scientists see the details they are interested in. Amateur astronomers nowadays also produce dazzling false-colour images of planetary nebulae.

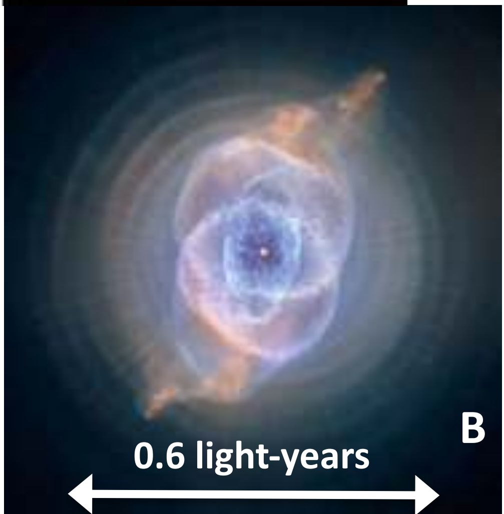
In reality, these objects, when seen in a telescope, look greenish. The first ones that were observed reminded astronomers of planets. Hence the name planetary nebulae.

But, as we will see in this booklet, planetary nebulae have nothing to do with planets; rather, they should be called ‘stellar nebulae’, being clouds of gas expelled by aging stars.

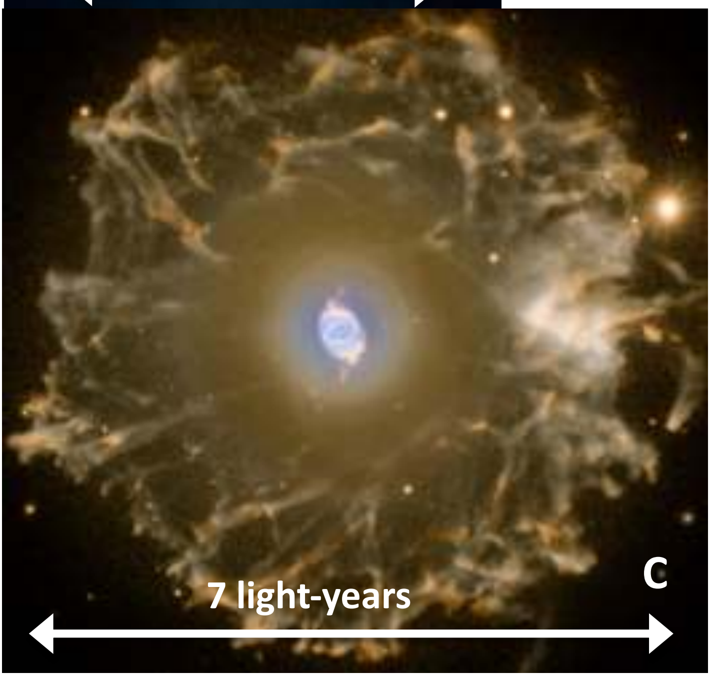


NGC 6543, the Cat's Eye Nebula

A) The bright core of the nebula, imaged by the Kitt Peak National Observatory 2.1m telescope.



B) Hubble Space Telescope image. The concentric rings show that the mass-loss process was once isotropic and periodic.



C) Image taken by R. Corradi with the Nordic Optical Telescope. The wide field of view and the long exposure reveal a faint, irregular massive halo.

The formation of a planetary nebula

Stars spend most of their lives burning hydrogen in their cores (see TUIMP 14). When hydrogen is exhausted, the star's core shrinks and the outer layers expand and cool: a red giant is formed.

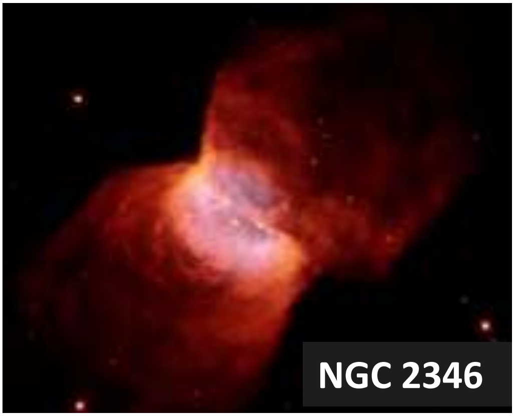
Then helium ignites in the core, leading to the synthesis of carbon and oxygen. If the star's initial mass is smaller than a few times Suns, the process ends with helium burning. The cool outer layers are expelled, creating a gas and dust envelope while the core shrinks to become a carbon-oxygen white dwarf.

The white dwarf is very hot and emits photons energetic enough to ionize the envelope, which then starts to shine: a planetary nebula appears. Its lifetime is determined by the star's cooling rate and the envelope's expansion. It is typically about 20,000 years.

MyCn18

This planetary nebula, discovered about a hundred years ago, became known as the 'hourglass' nebula after this Hubble Space Telescope image was published. Its binary central star may be the cause of the spectacular bipolar shape of the nebula.

This bipolar nebula also has two central stars. Only one of them is hot enough to ionize the nebula but the shape of the nebula results from the action of both.



NGC 2346

IC 418

This nebula has been dubbed 'the spirograph nebula' after the Hubble Space Telescope revealed its filamentary structure, likely due to magnetic fields.

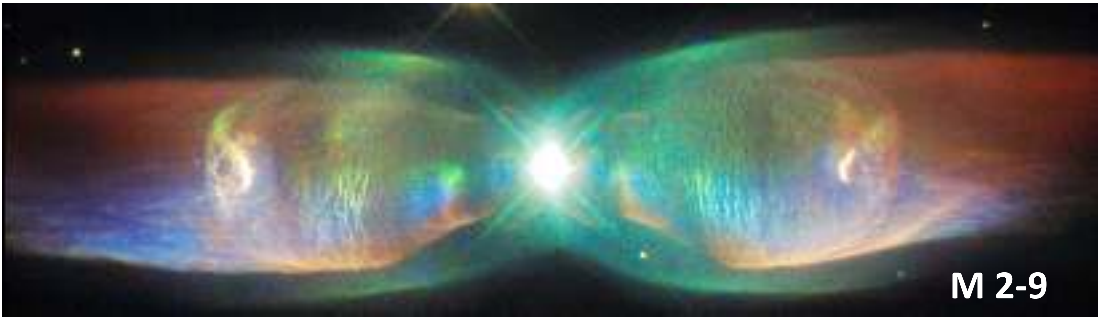
A more detailed view

In fact, it is when the fast wind coming from the aging central star catches up with the slower wind of the previous red giant phase that a dense shell is formed, which will become a planetary nebula.

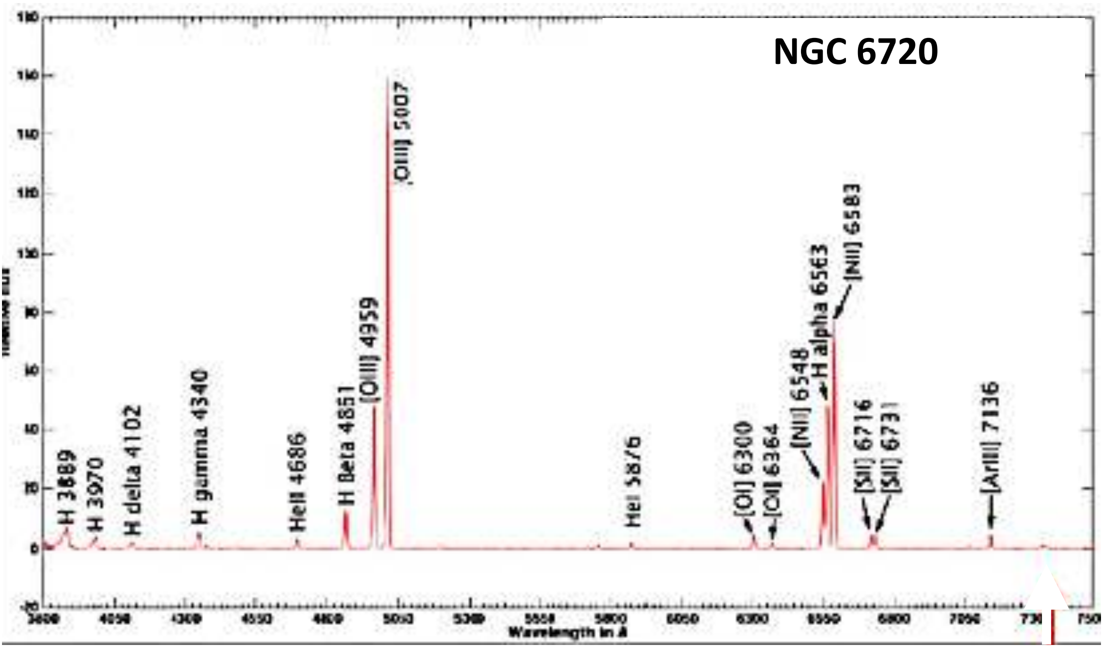
Many planetary nebulae, however, are far from spherical, which suggests that they cannot have been formed by the evolution of a single star.

Indeed, some 'central' stars are actually double stars, revolving around each other. As one star begins to shed its outer layers, the gravitational forces exerted by its companion distort the nebula, creating aspherical shapes. Additionally, mass transfer between the stars can give rise to jet-like structures.

Magnetic fields may also affect the shapes seen in planetary nebulae.



A Hubble Space Telescope image of the bipolar planetary nebula M 2-9, sometimes called 'the butterfly nebula'. It prompted a very detailed hydrodynamical study aimed at reproducing the evolution of the nebular lobes and the knots of emission within



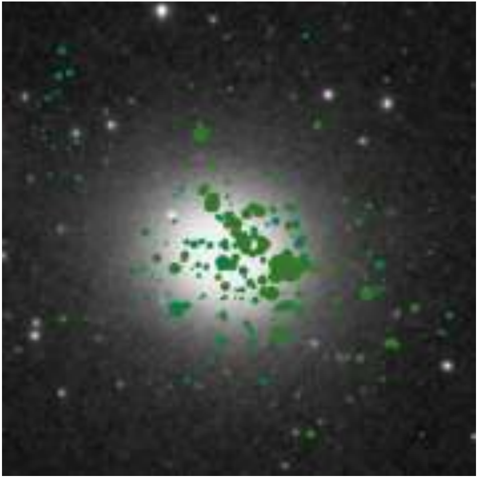
A spectrum of the Ring Nebula showing the presence of hydrogen, helium, oxygen, nitrogen, sulfur and argon.

Usefulness of planetary nebulae

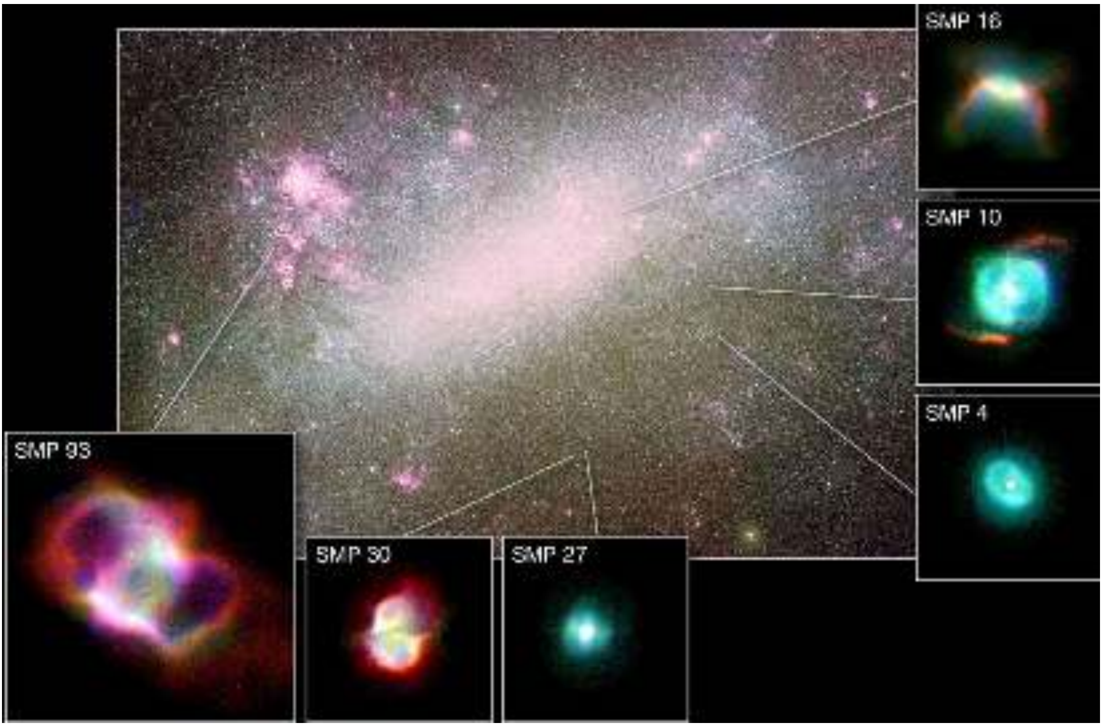
Planetary nebulae, even if not spherical, have simpler geometries than other types of nebulae, making them more amenable to analysis, in particular of their dynamics.

Using their spectra (see TUIMP 30), astronomers can identify what elements they are made of. This allows the determination of the chemical composition of the interstellar medium when the parent stars were born. This also enables astronomers to measure the amounts of elements as carbon, krypton, or xenon, which are produced by these stars.

The methods used to measure chemical abundances were devised about 80 years ago. They rely on data computed by atomic physicists and are still being refined today.



The elliptical galaxy NGC 3379. The green dots mark the positions of planetary nebulae detected by the PN.spectrograph. Measurement of their radial velocities allows the determination of the kinematics of the galactic halo well beyond the region shown in the image.



The Large Magellanic Cloud and the positions of a few planetary nebulae of various morphologies.

Planetary nebulae in other galaxies

The spectra of planetary nebulae are very different from those of other objects (see TUIMP 30), with just a few very strong lines, easy to identify, that emit all the light. This is why it is possible to recognize planetary nebulae in distant galaxies, even if their shapes cannot be resolved.

Planetary nebulae are easily detected in the halos of galaxies and their velocities can be measured through the Doppler effect (see TUIMP 15). They serve as tracers of the dynamics of galactic halos, and allow us to determine the halo mass.

Note that the light coming from galaxies takes time to reach the Earth. From the Magellanic Clouds, our closest neighbours, it takes 150,000 yr. This means that the planetary nebulae are already dead when astronomers observe them !

A few artworks representing the death of the Sun as a planetary nebula.

Above:
Credit Regulus36/ deviantart, adjusted by DM to mitigate compression effects

Right:
Credit Joe Tucciarone

Left:
Credit DETLEV VAN RAVENSWAAY / SCIENCE PHOTO LIBRARY

Will the Sun create a planetary nebula ?

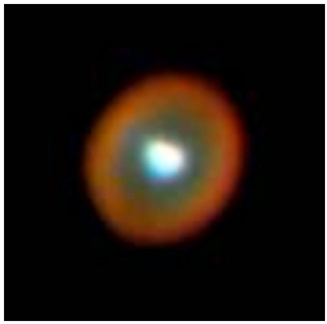
The Sun is a normal star. Its mass corresponds to that of progenitors of red giants and white dwarfs. Will it create its own planetary nebula?

Some astronomers think so, and have even conjectured that this planetary nebula would be elliptical and not spherical, due to the gravitational pull of Jupiter.

However, the creation of a planetary nebula requires a fine-tuning between the pace at which the star's external layers are expelled and the time required for the stellar remnant to be hot enough to ionize its lost envelope. This fine-tuning may or may not happen for the Sun.

Anyway, this would not take place before 5 billion years, after the cold atmosphere of the Sun's red giant would have engulfed all of the inner planets.

All these photos were made by amateur astronomers. Only one does not represent a planetary nebula.

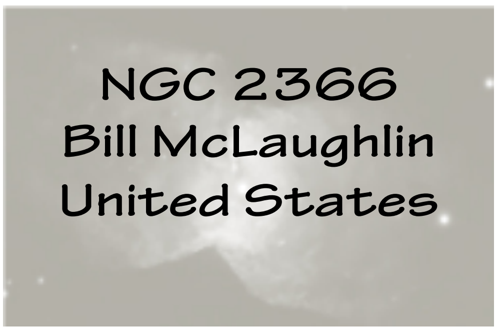


Which one?

Solution on overleaf

The Crab Nebula is a supernova remnant

(see TUIMP 10)



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This booklet was written in 2023 by Grażyna Stasińska from Paris Observatory and revised by Stan Kurtz, from UNAM, Mexico.

Cover image: Hubble Space Telescope image of the centre of the Cat's Eye Nebula.
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All the images in this booklet, unless otherwise stated, are from the Hubble Space Telescope (NASA, ESA).

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