The Life of Stars

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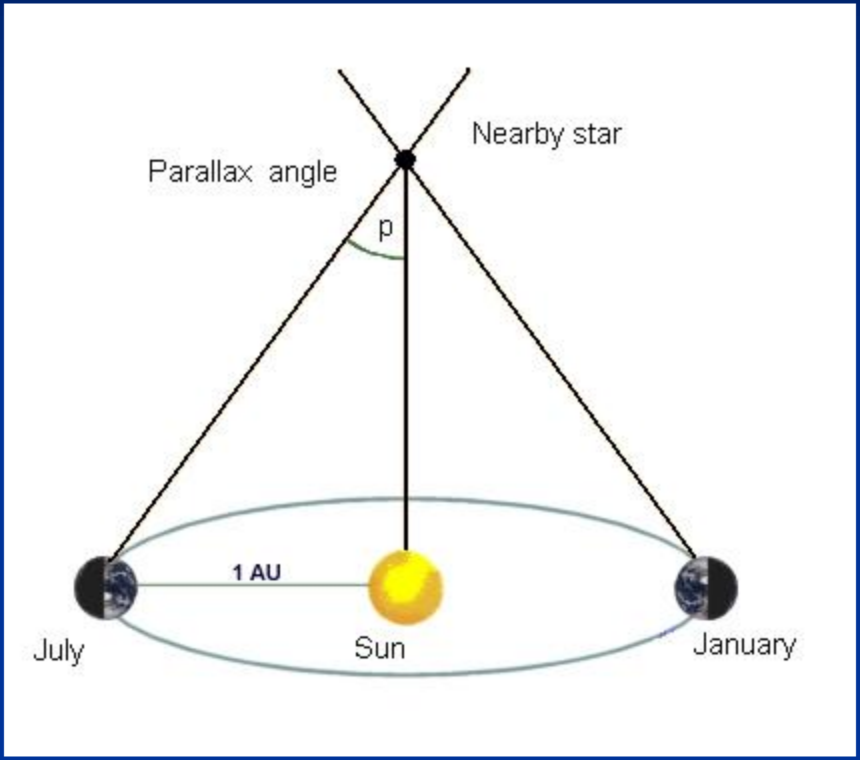
Goals

- Understand the difference between apparent magnitude and absolute magnitude.
- Understand the Hertzsprung-Russell diagram - a color /magnitude diagram.
- Understand concepts such as supernova, neutron star, black hole and pulsar.

Activity 1: Simulating parallax

- Keep your thumb pointing upward with your arm outstretched.
- Keep looking, first only with your left eye open, then only with your right eye. What do you see?
- Now move your finger halfway up to your nose and repeat the observation. What do you see?

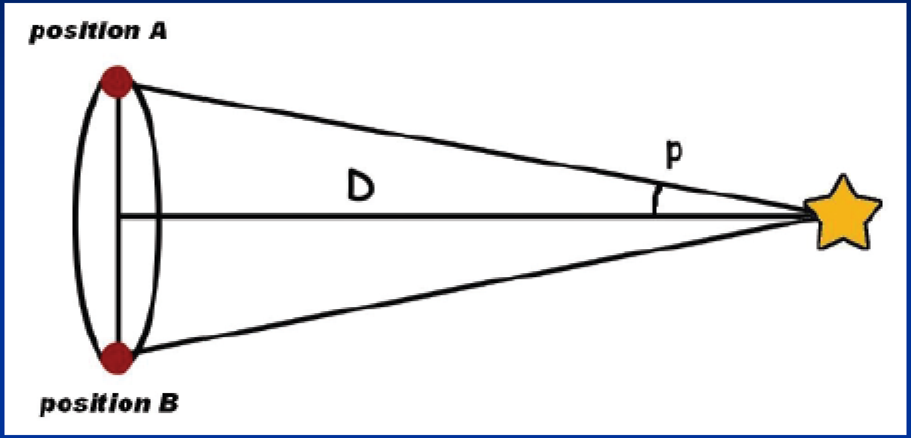
Parallax



Source: Columbia University.

- Parallax is the apparent difference in the position of an object when viewed from different locations.
- The position of a nearby star on the sky appears to change when viewed from Earth now and then six months later.
- Thus we can measure the distance to nearby stars.

Parallax



$$D = \frac{AB/2}{\tan p} = \frac{AB/2}{p}$$

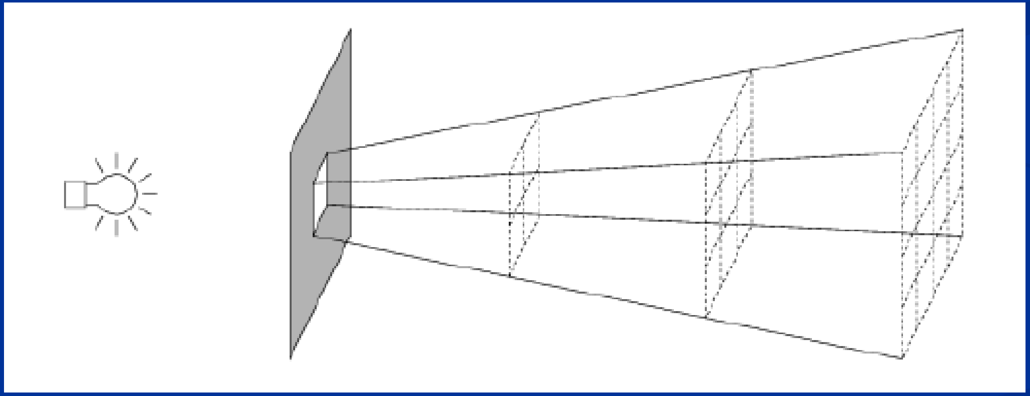
$$D \cong \frac{150\,000\,000}{2\pi/(360^{o}x60x60)} = 30\,939\,720\,937\,064 \text{ km} = 3{,}26 \text{ l.y.}$$

1 parsec = 3.26 light years

d = 1/p

Activity 2: Law of inverse square

A star emits radiation in all directions. The intensity (I) received at a distance D, per unit of surface area, is the luminosity L (power) of the star, divided by the area of a sphere centred on the star.



$$I = \frac{L}{4\pi D^2}$$

Activity 2: Law of inverse square

When the distance is doubled, the corresponding area is four times larger, and the light intensity (the incident light per unit area) will become four times smaller.

The intensity of light is inversely proportional to the square of the distance from the source.

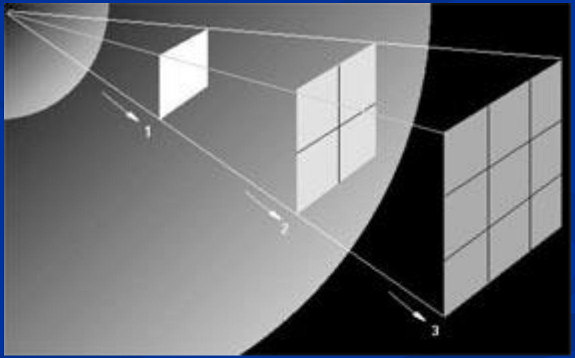
System of magnitudes

The stars show different brightnesses.

The brightest star that you see may be of small luminosity and be close, or of large luminosity and be distant.

The brightness is defined as :

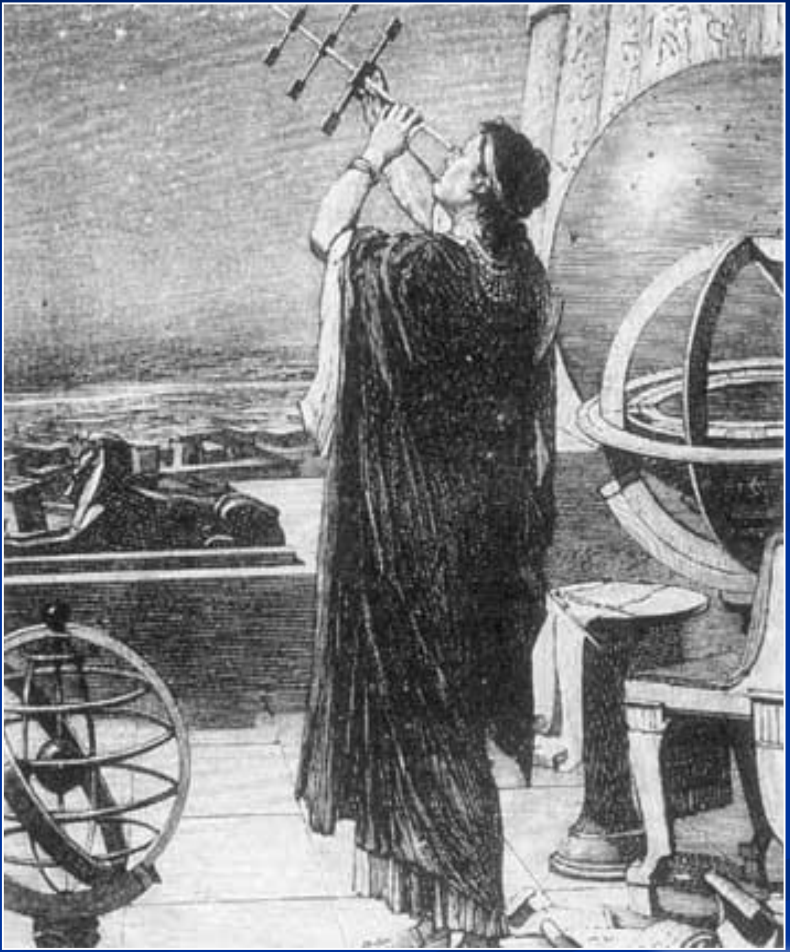
$$B = \frac{L}{4\pi D^2}$$



System of magnitudes

Hipparchus was born in Nicaea (now known as Iznik, Turkey) in 190 BC. It is believed that he died in Rhodes, Greece, in 120 BC.

About 125 years BC, he defined the system of magnitudes.



System of magnitudes

Hipparchus called the brightest stars 1st magnitude, those less bright 2nd magnitude and continued until the faintest, which he called 6th magnitude.

That system, slightly changed, is used today: the greater the magnitude, fainter the star.

Astronomers refer to the brightness of a star when talking about its magnitude.

System of magnitudes

In 1850, Robert Pogson suggested that a difference of 5 magnitudes should be exactly equal to the brightness ratio of 100 to 1.

This is the formal definition of the magnitude scale that is used by astronomers today.

Pogson's Law

From the computational point of view, it is useful to use the logarithmic scale to write this relation:

$$2.5 \log (B_1/B_2) = m_2 - m_1$$

For example:

- Sirius, the brightest star on the sky, has a magnitude of -1.5
- The magnitude of Venus is -4
- The magnitude of the Moon is -13
- The magnitude of the Sun is -26.8

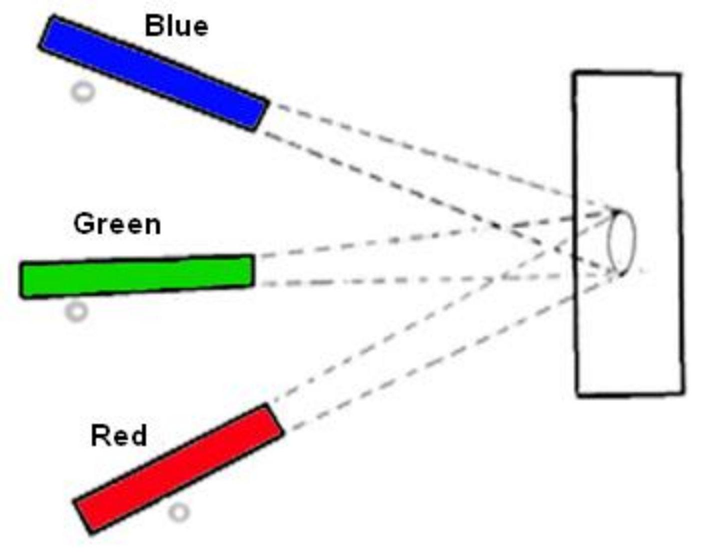
Apparent and absolute magnitude

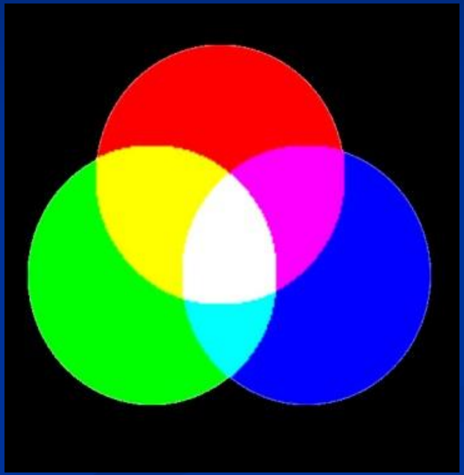
- A very powerful but distant star can have the same Apparent Magnitude (m) as another fainter star but closer star.
- Astronomers have established the concept of Absolute Magnitude (M) where the star is imagined to be at a distance of 10 parsecs (32.6 light years) from us.
- With the Absolute Magnitude we can now compare the "real brightness" of two stars, or equivalent to it, its power or luminosity.
- The mathematical relationship between m and M is:

$$M = m + 5 - 5 \log d$$

where d is the real distance to the star.

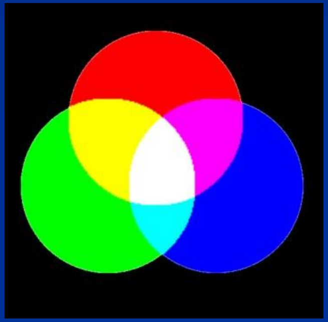
Activity 3: stellar colors

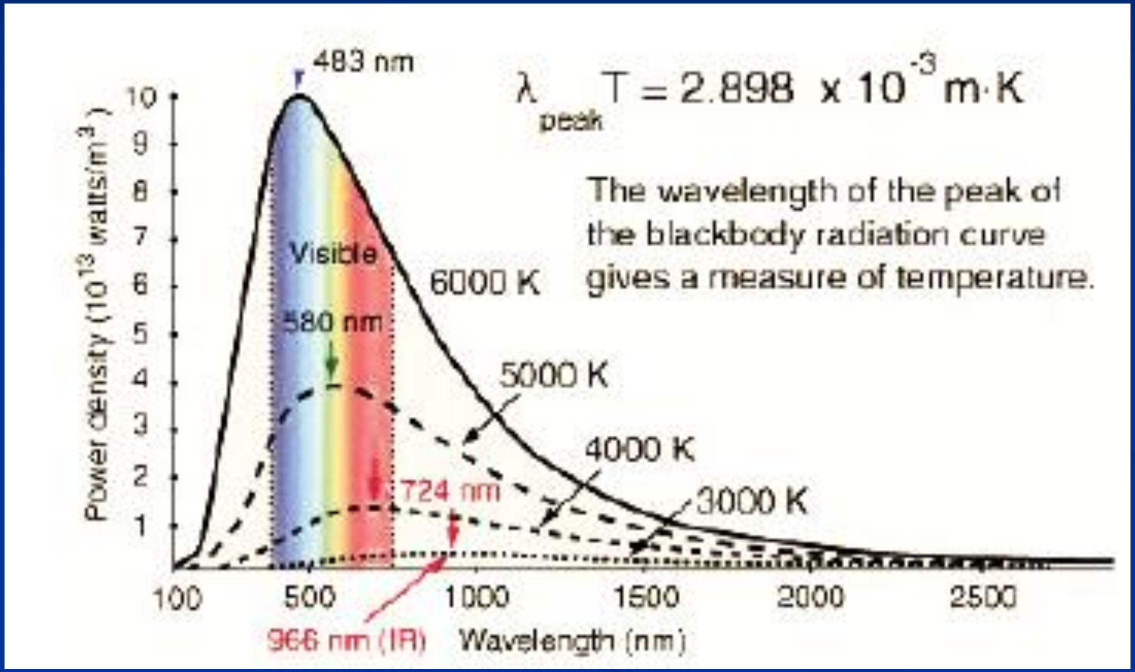




Activity 3: Stellar colours

The stars show different colors according to their temperature

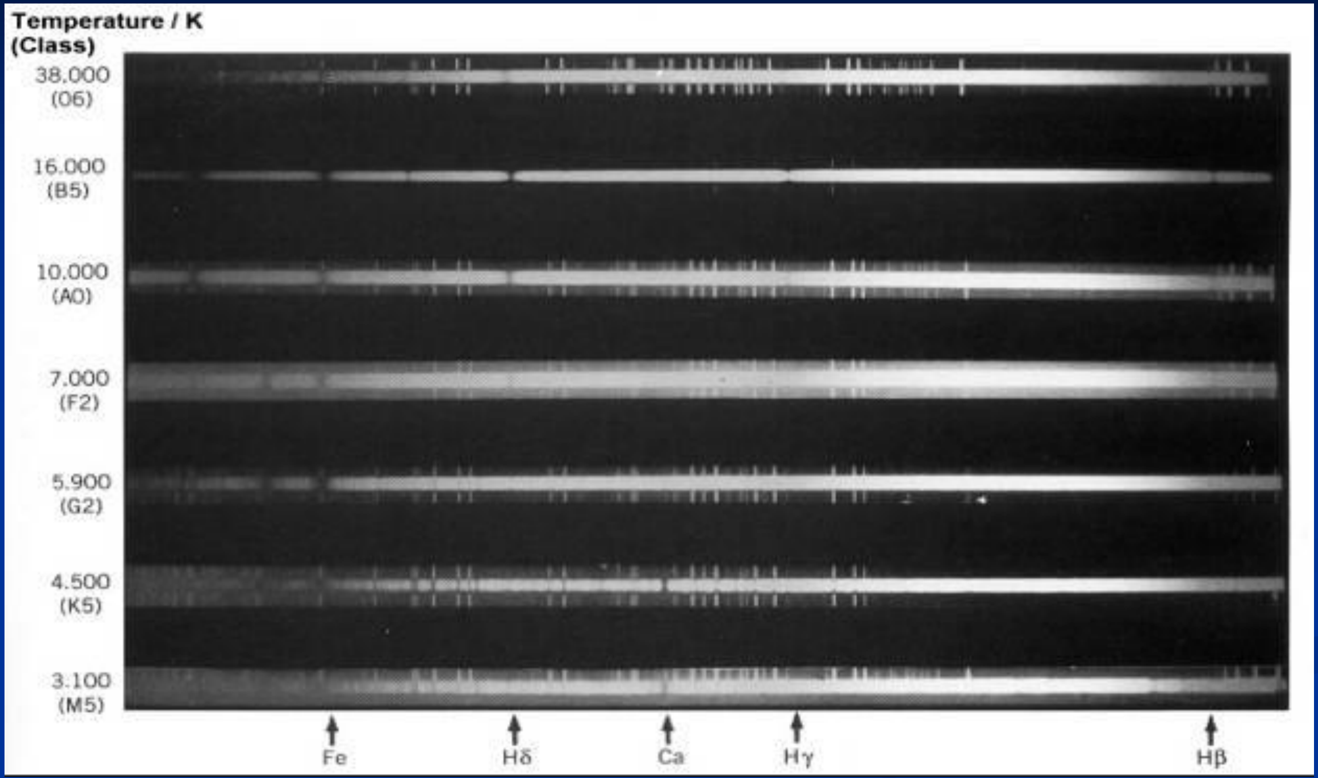




Intermediate temperature stars present maximum emission in green light, but they also emit a lot of red and blue light, the result is an average of the visible wavelengths and the sum of all the colors of the spectrum is white.

That is why there are no green stars!

Spectral classes



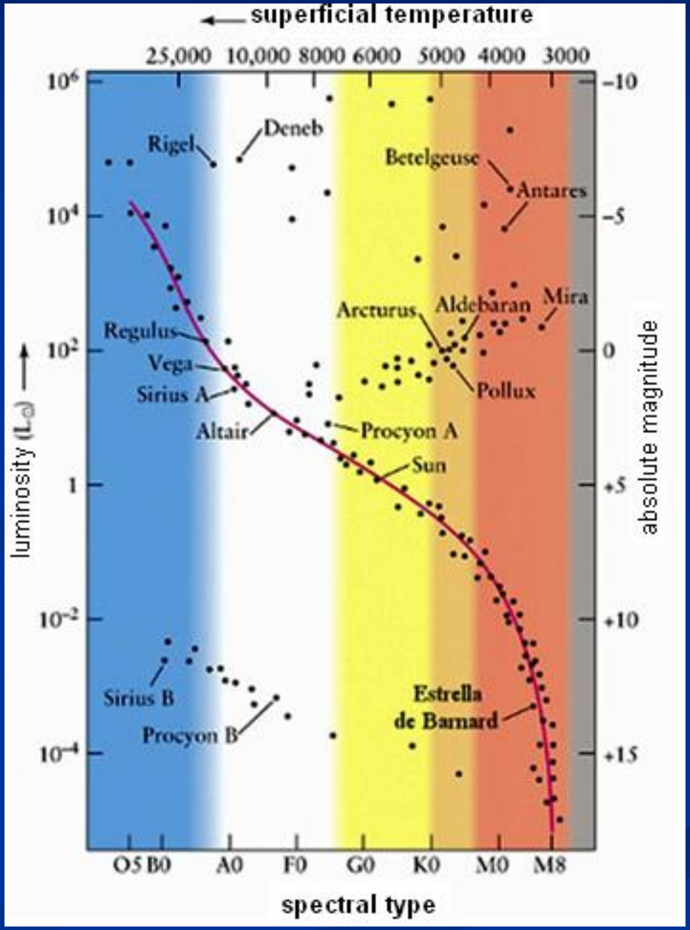
Relationship between spectral classification, temperature and color of stars.

Hertzsprung-Russell Diagram

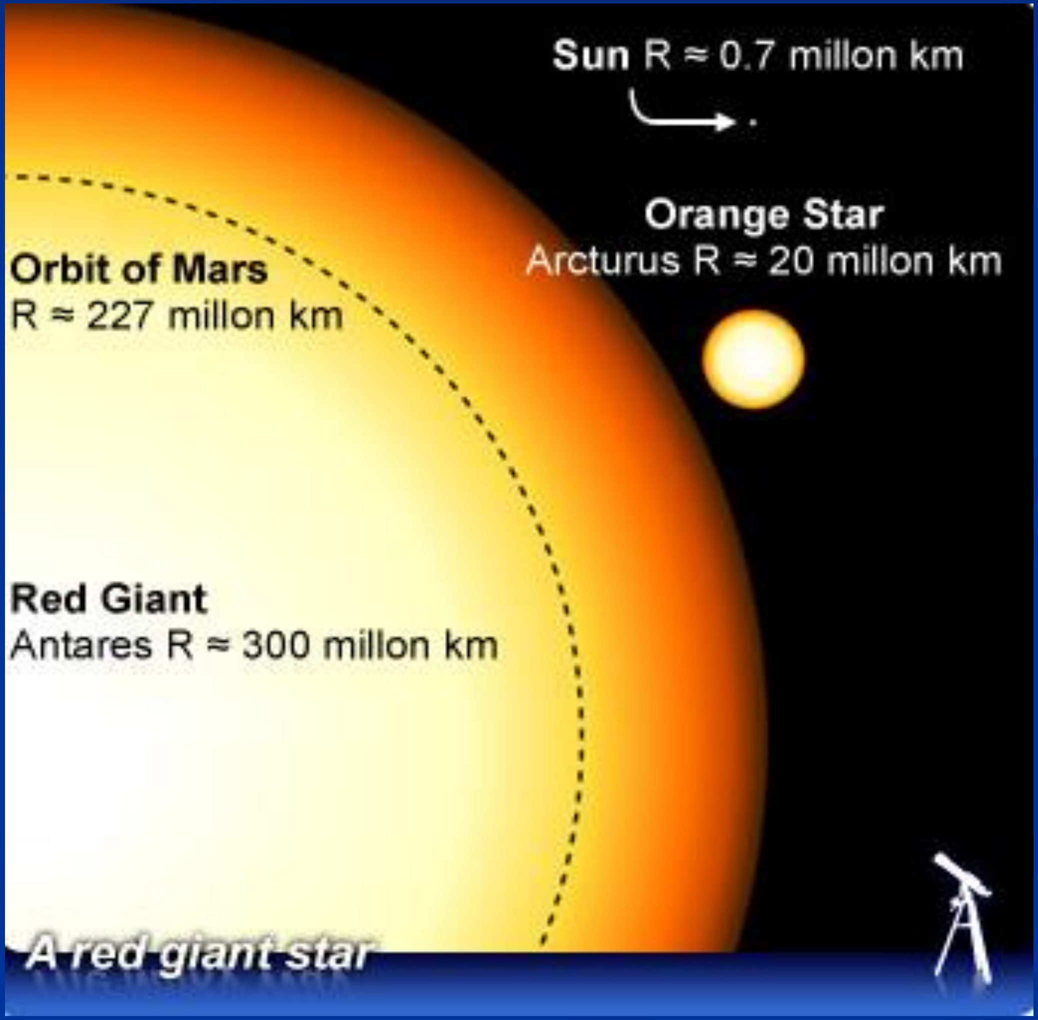
The stars can be represented in an empirical diagram using their surface temperature (or spectral type) in function of their brightness (or absolute magnitude).

In general, the stars occupy certain regions of the diagram.

The star position helps you to know the type of star and its evolutionary stage.



Stellar Evolution
Formation of a Red Giant

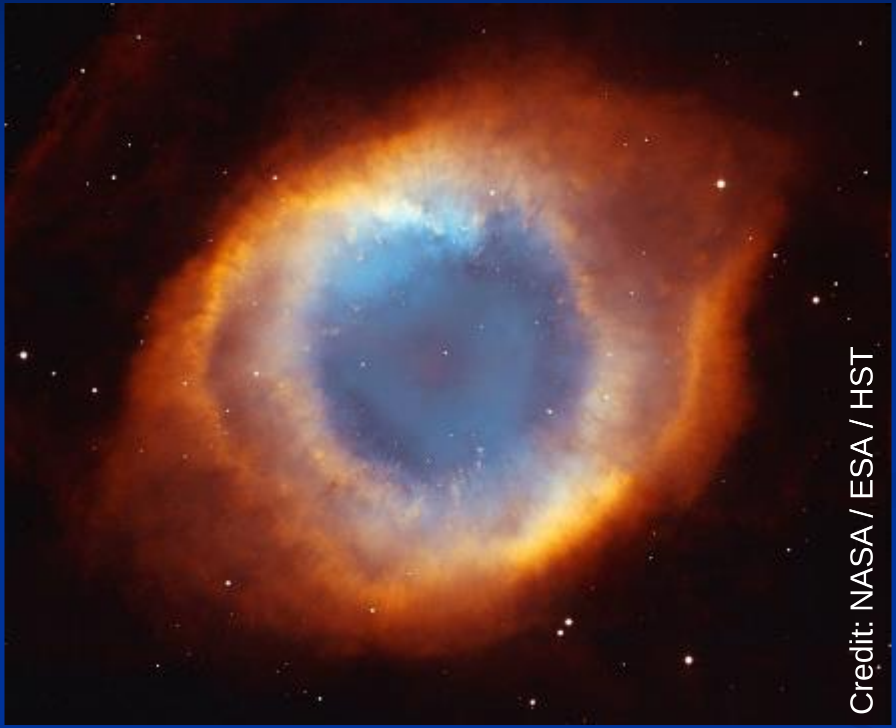


The stars evolve in different ways depending on their mass.

Stellar Evolution
Formation of the White Dwarf

A star of low or intermediate mass such as the Sun, evolves into a white dwarf This is a form of non-catastrophic stellar death.

Helix Nebula



The central object, small and white is a white dwarf, a dead star, which no longer produces energy by fusion and is visible only due to its very high temperature.

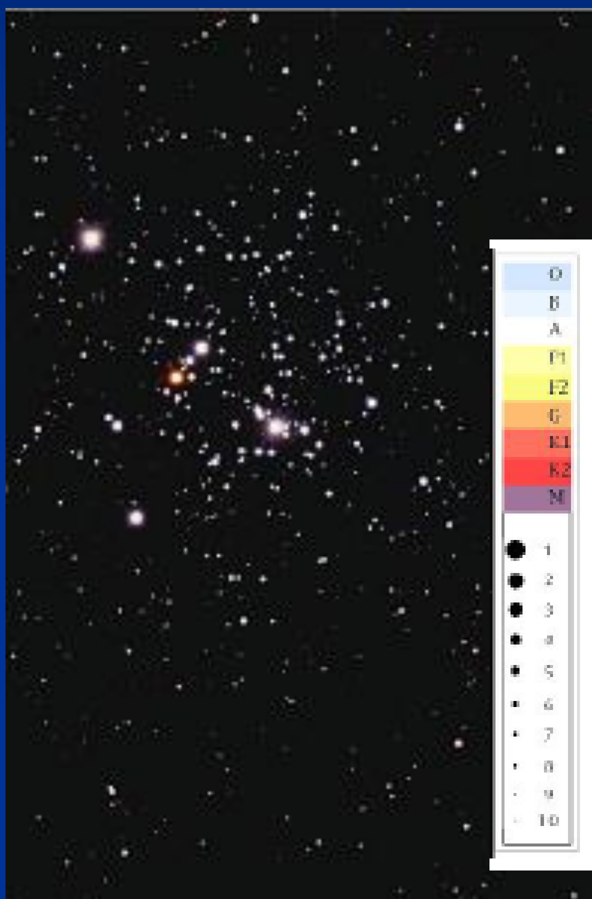
Cat's Eye Nebula

The Cat's Eye Nebula is a planetary nebula of great beauty. Here you can see the photo in the visible region (left, Hubble Space Telescope) and X-rays (right, Chandra telescope).

Activity 4: The age of the open clusters

You can determine the age of a stellar cluster by comparing the HR diagram with other diagrams of clusters whose ages are known.

Activity 4: The age of the open clusters



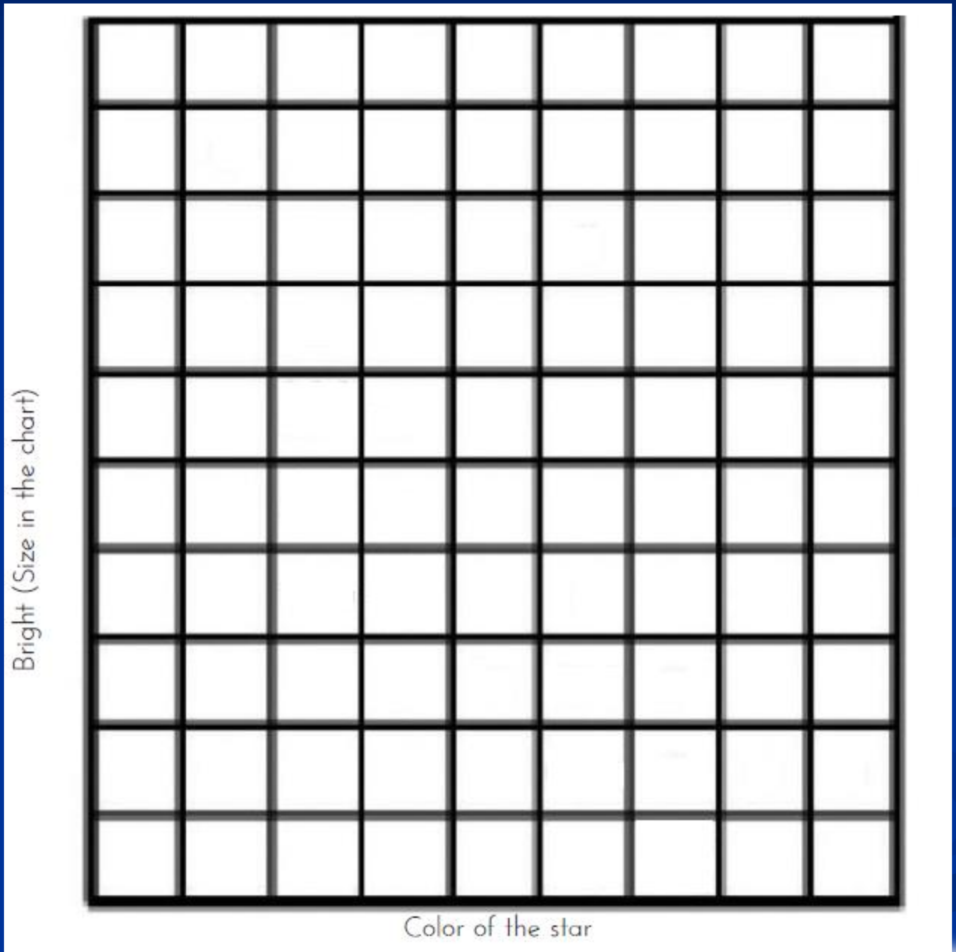
Kappa Crucis

- Draw a square of 4 cm of side centred on the cluster.
- Measure the brightness of the chosen star by comparing it with the points in the guide.
- Estimate the colour of the chosen star using the colour guide for comparison.

Activity 4: The age of the open clusters

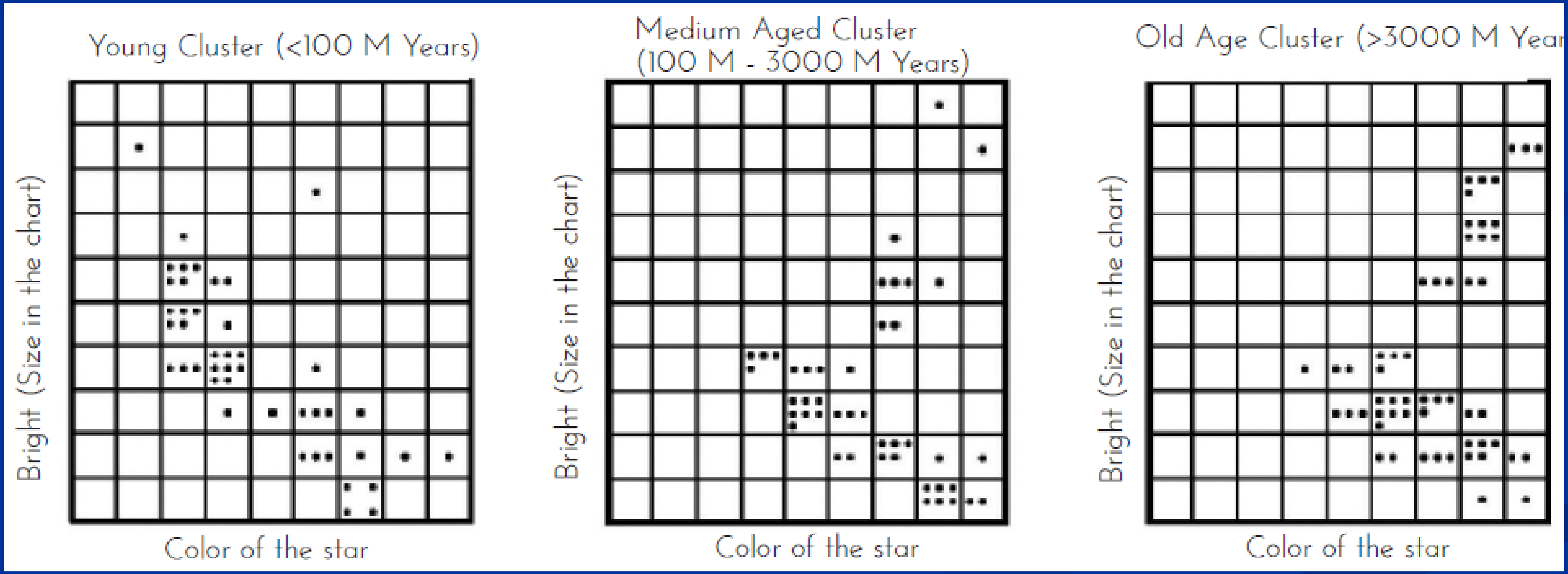
- Locate that star in the grid on the right.

- Repeat with other stars.

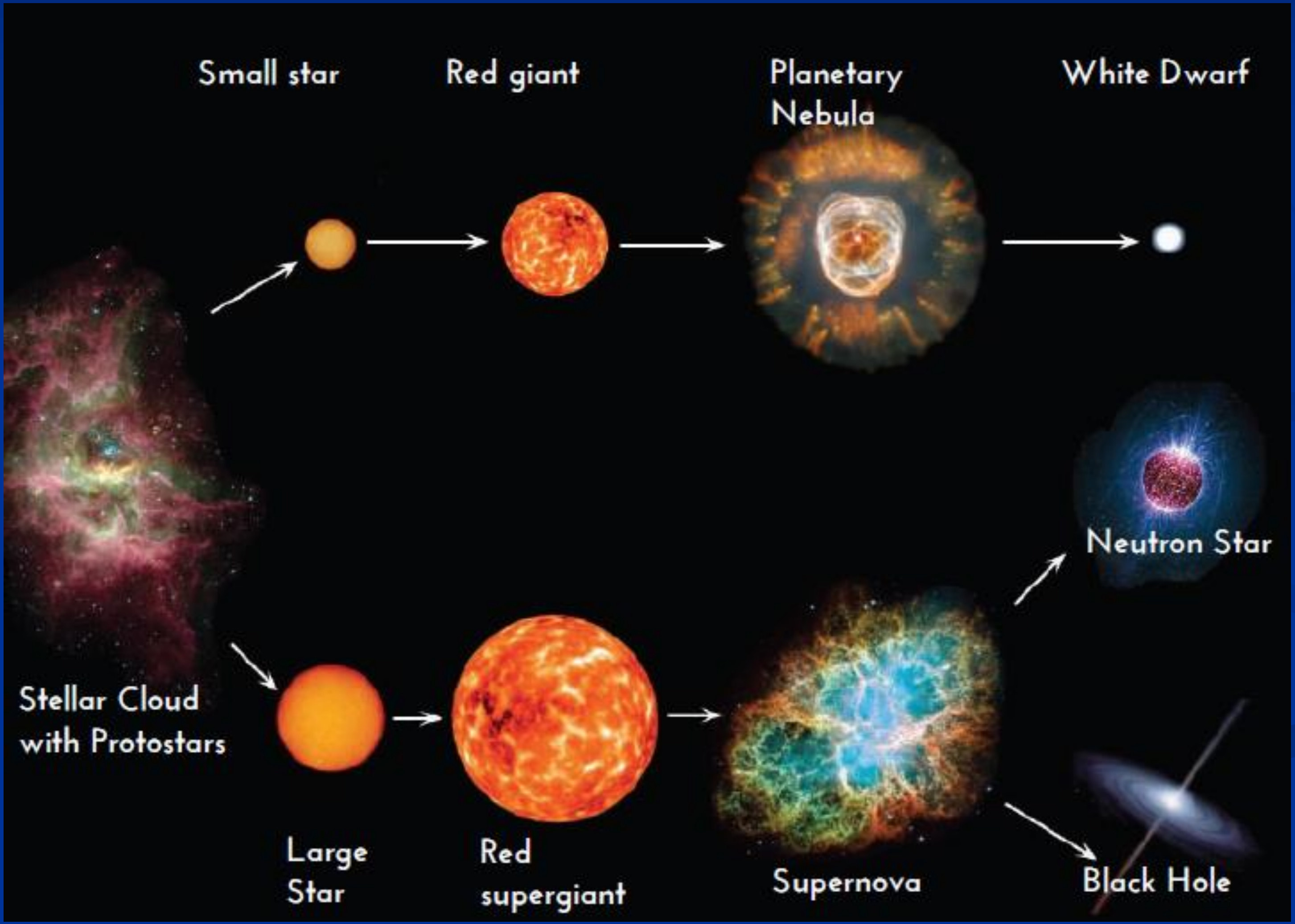


Activity 4: The age of the open clusters

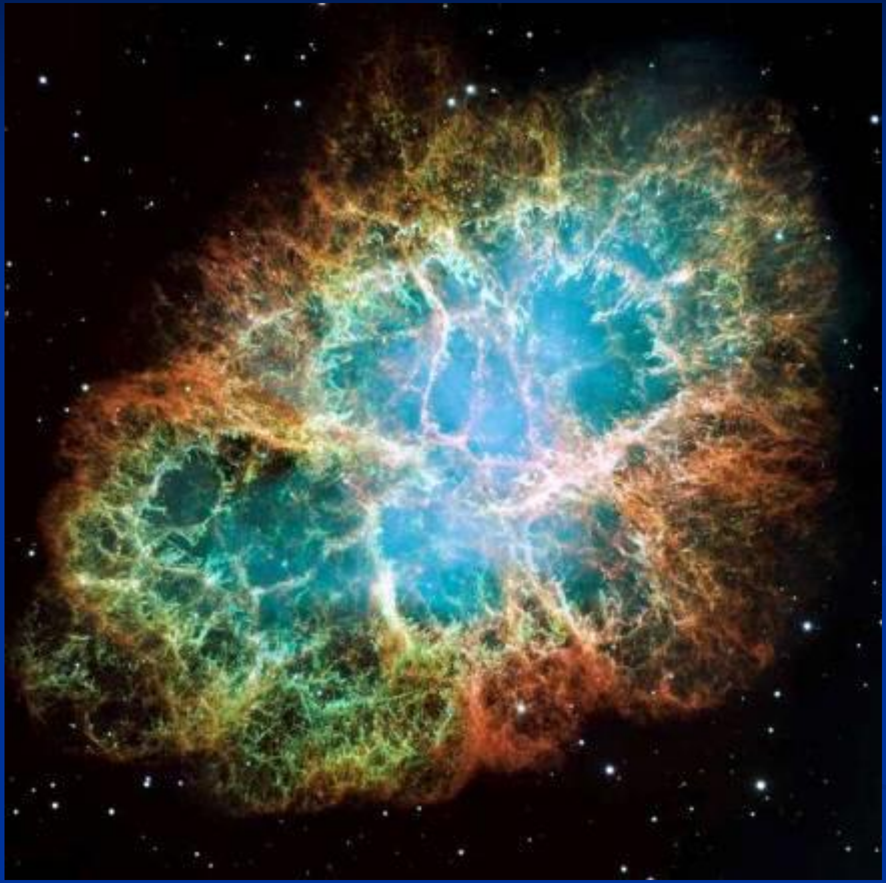
Compare your measured diagram with the ones below. How old is your cluster?



Relation between the mass and the death of the stars

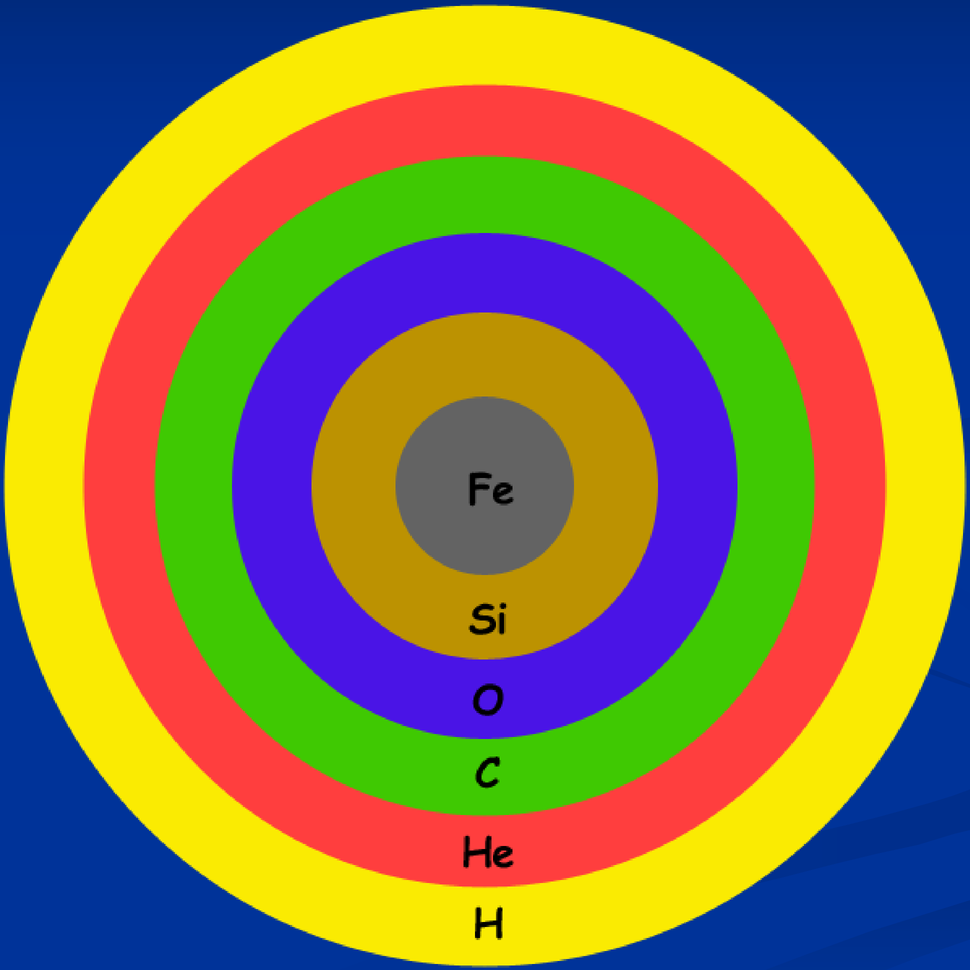


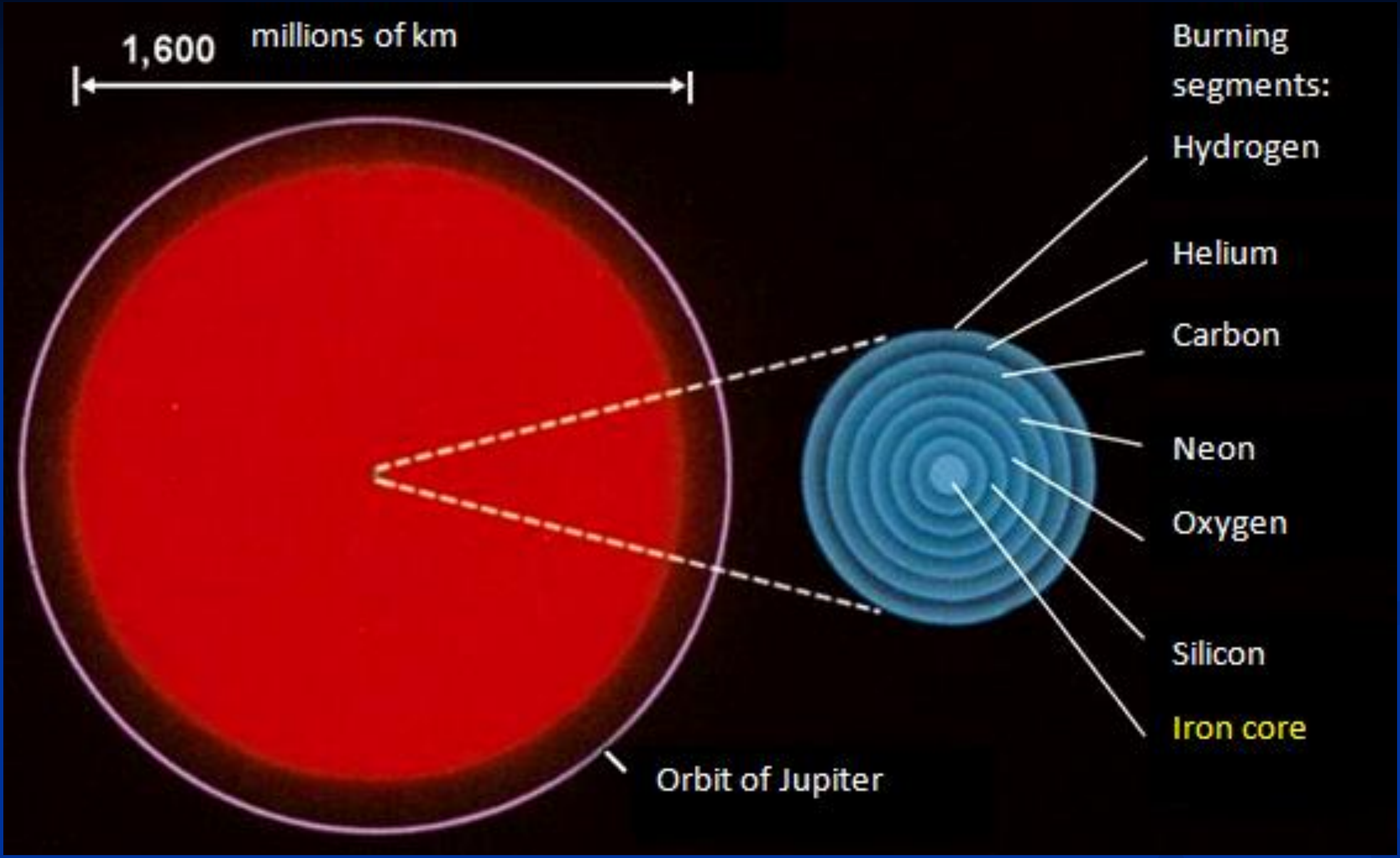
The death of massive stars



M1: The Crab Nebula in Taurus, is the remnant of the supernova observed in 1054 AD.

Star ready to explode as a supernova



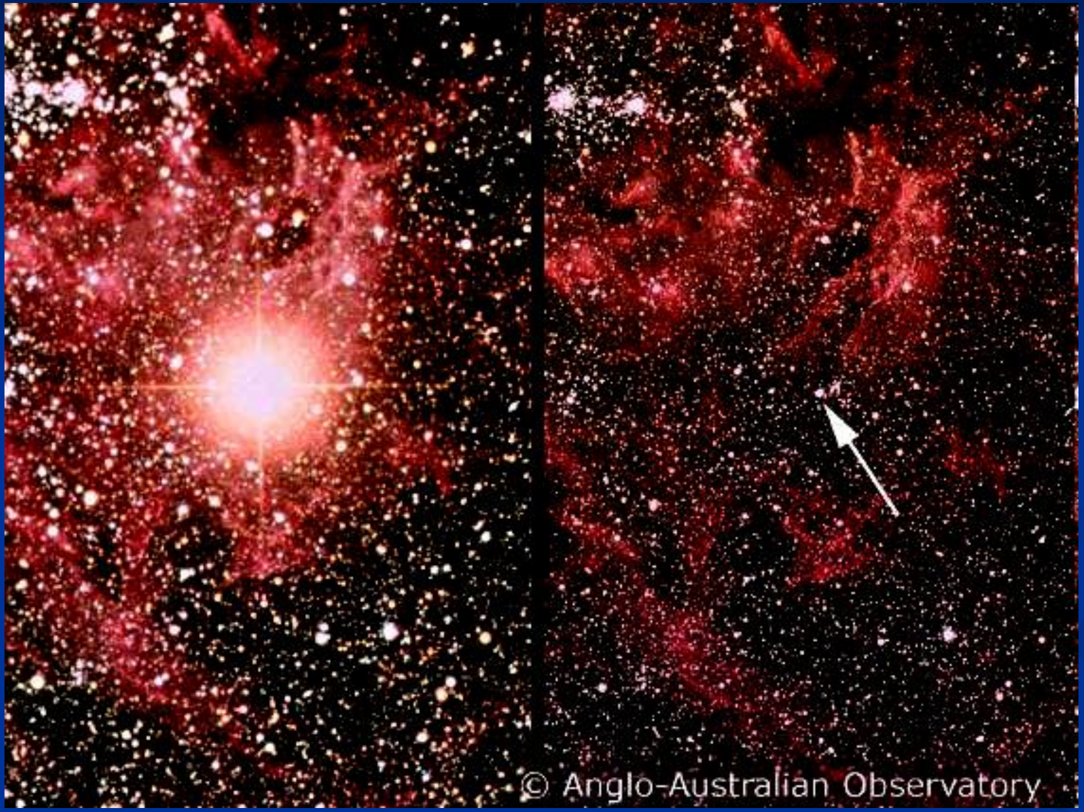


Characteristics of a star ready to explode as a supernova

A star of 20 solar masses lasts:

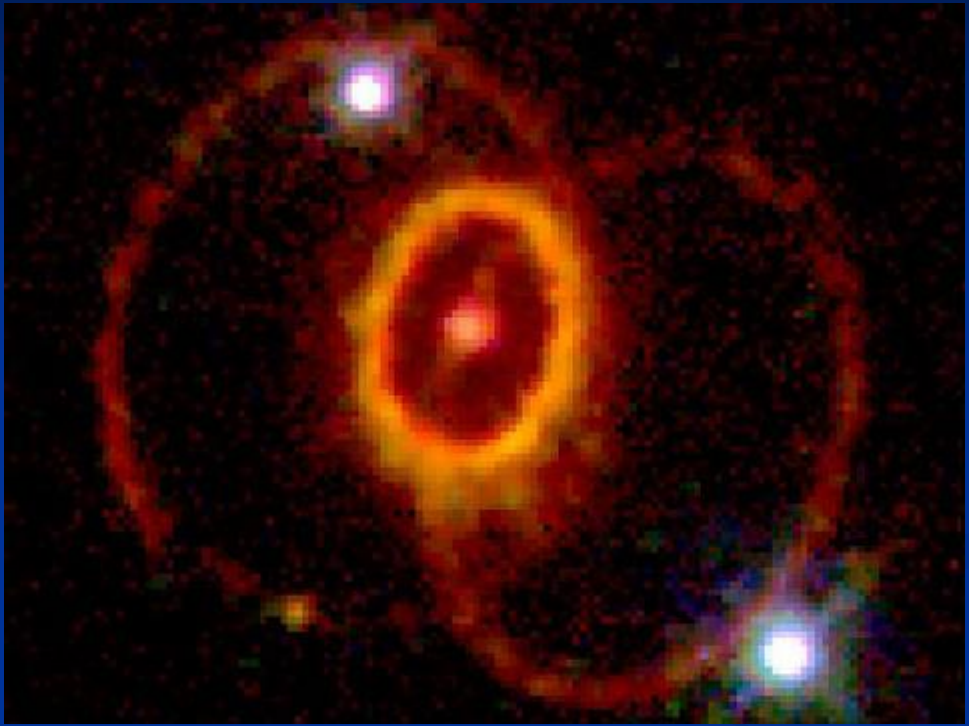
- 10 million years fusing hydrogen into helium inside its core (main sequence)
- 1 million years burning (fusing) helium
- 300 years burning (fusing) carbon
- 200 days burning (fusing) oxygen
- 2 days in consuming silicon: then the explosion of the supernova is imminent.

Supernova 1987A



The supernova 1987A was observed in 1987 in the Large Magellanic Cloud. The cloud is at 168,000 l.y. The light need 168 years to reach the Earth.

Supernova 1987A 10 years later



The material ejected after the explosion moves away at high speed away from the star.

This photo of SN 1987A was taken by the Hubble Space Telescope in 1997.

Examples of supernovae in a distant galaxy. On average, in each galaxy, one supernova forms per century.

In the Milky Way, there have been no detections of supernovae over the last 400 years.

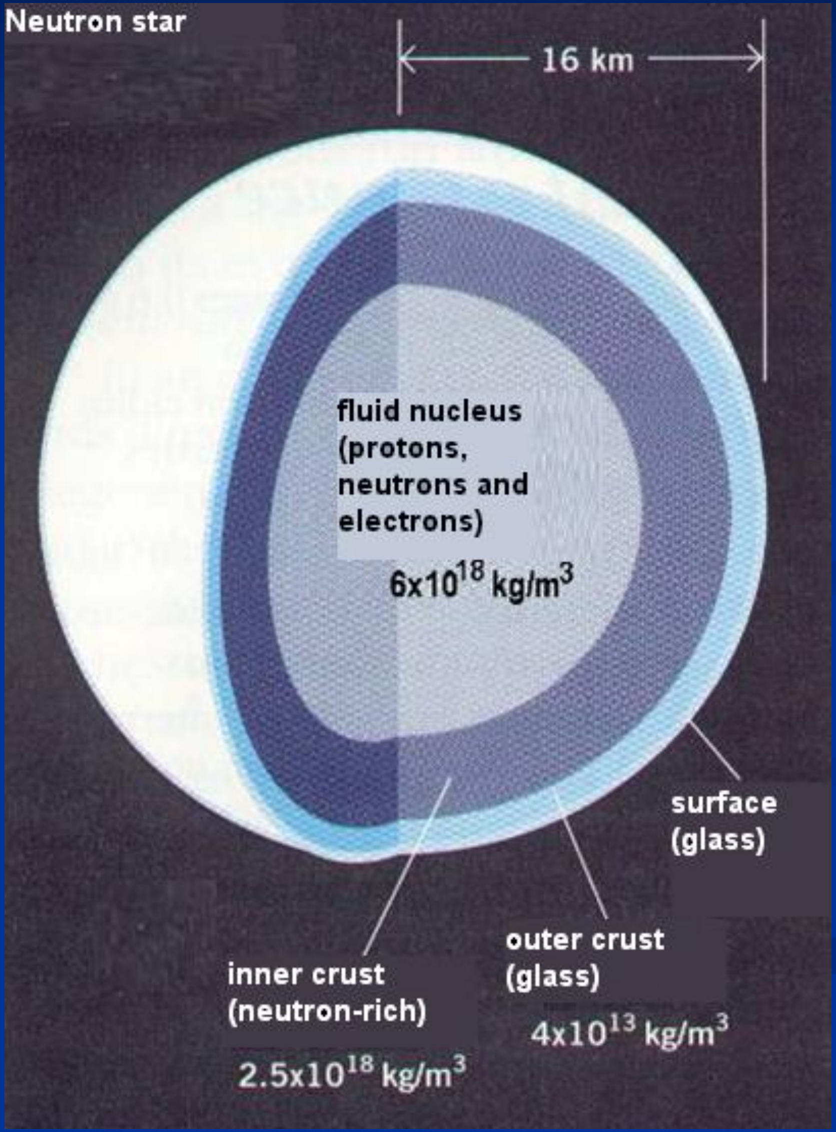
Activity 5: Simulation of the supernova explosion

When a star explodes as a supernova, the light atoms of the outer layers fall into the inner heavier atoms. They then bounce off the solid core.

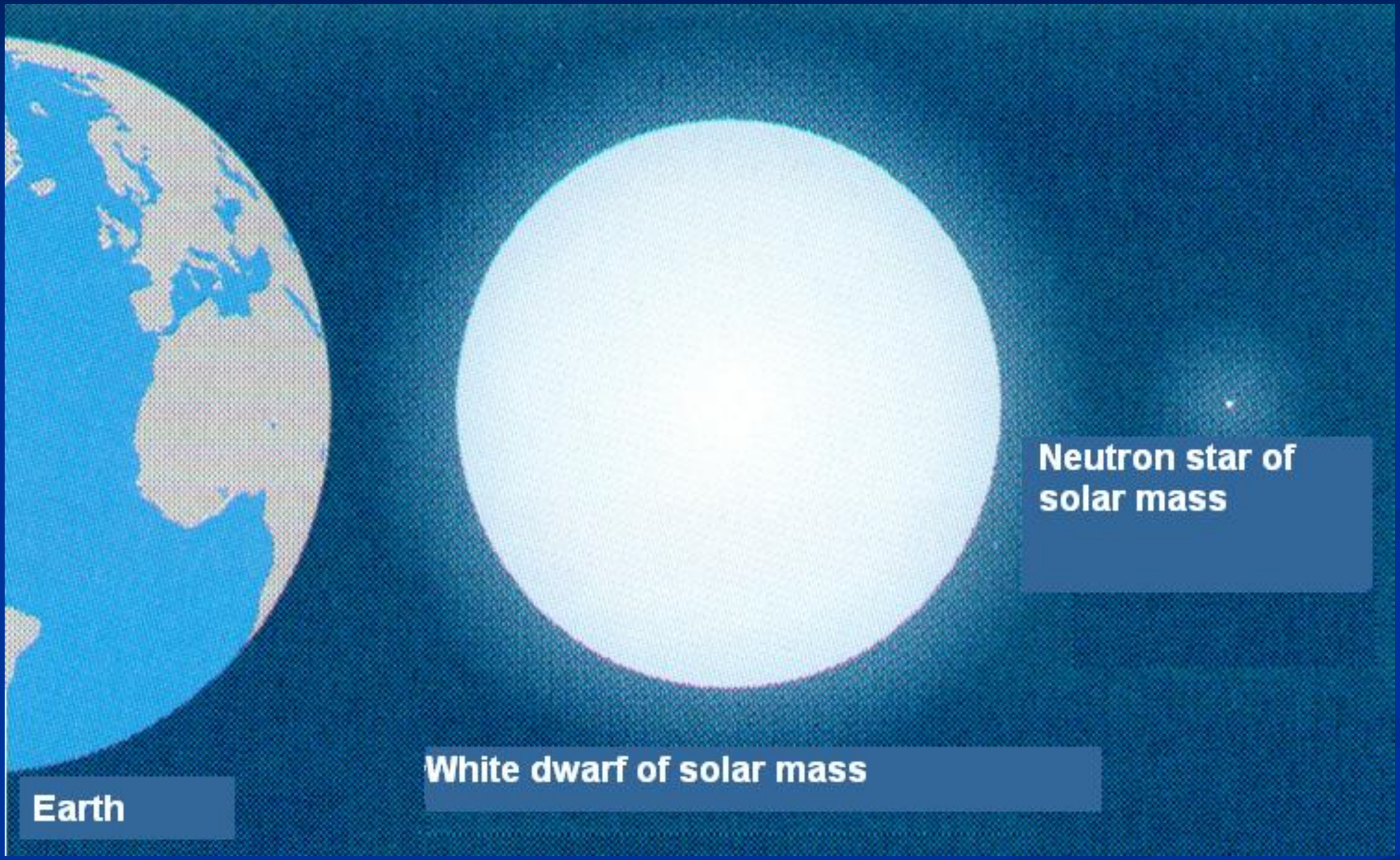
In this model, the floor represents the solid core of a neutron star. The basketball would be a heavy bouncing atom, which pushes the light atom that comes from above, represented by the tennis ball.

Neutron Stars

Another form of stellar death is the neutron stars or the pulsars

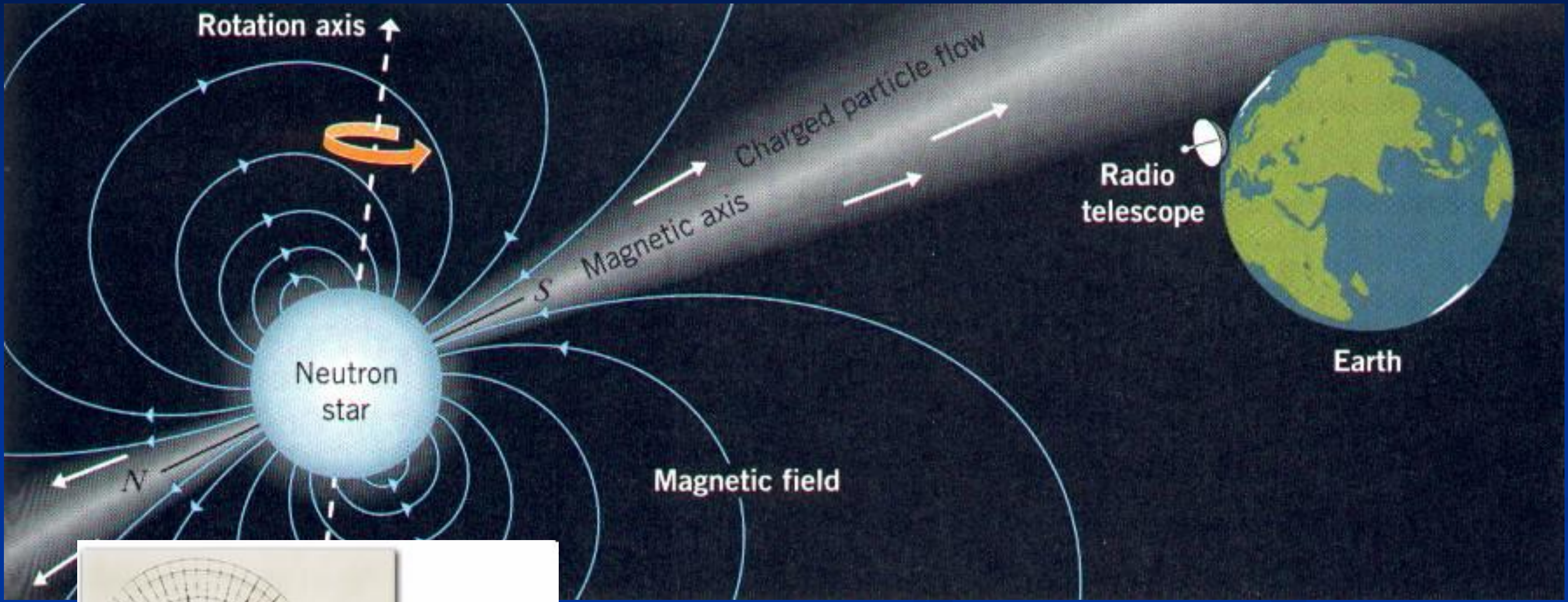


Neutron Stars



Size Comparison

Pulsars



How the radiation emitted by a pulsar is seen from the Earth.

Jocelyn Bell Burnell, the discoverer of pulsars in 1967.

Activity 6: Simulation of a pulsar

A pulsar is a neutron star, very massive and rotating rapidly. It emits radiation but the source is not fully aligned with the axis of rotation, so that the emission spins as a lighthouse.

If the beam is oriented towards the Earth, we see a variable radiation that repeats several times per second.

Mounting

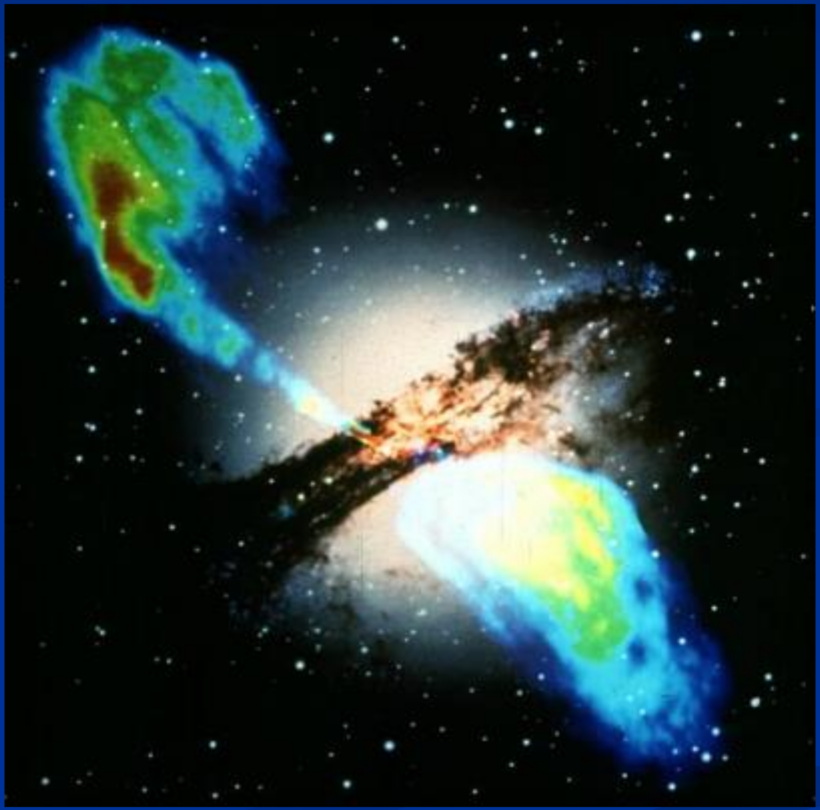
Turning

3rd form of stellar death: Black Holes

John Mitchell and Simon Laplace proposed the possibility of the gravitational collapse of supermassive objects at the end of their life.

They called these objects black holes, being invisible in the optical range, since their gravitational force is so big that nothing can escape from them, not even the light.

Stellar Evolution: Black Holes



There are supermassive black holes at the centres of galaxies

Activity 7: Simulation of the curvature of space and of a black hole

It is possible to simulate the curvature of space created by a black hole using a piece of elastic fabric (Lycra) and a water balloon.

The path of the tennis ball is not in a straight line but a curve.

Activity 7: Simulation of the curvature of space and of a black hole

An elastic net sold in pharmacies can be also used.

If we loosen the elastic net, the well is greater and it simulates a black hole.

Thank you very much
for your attention!