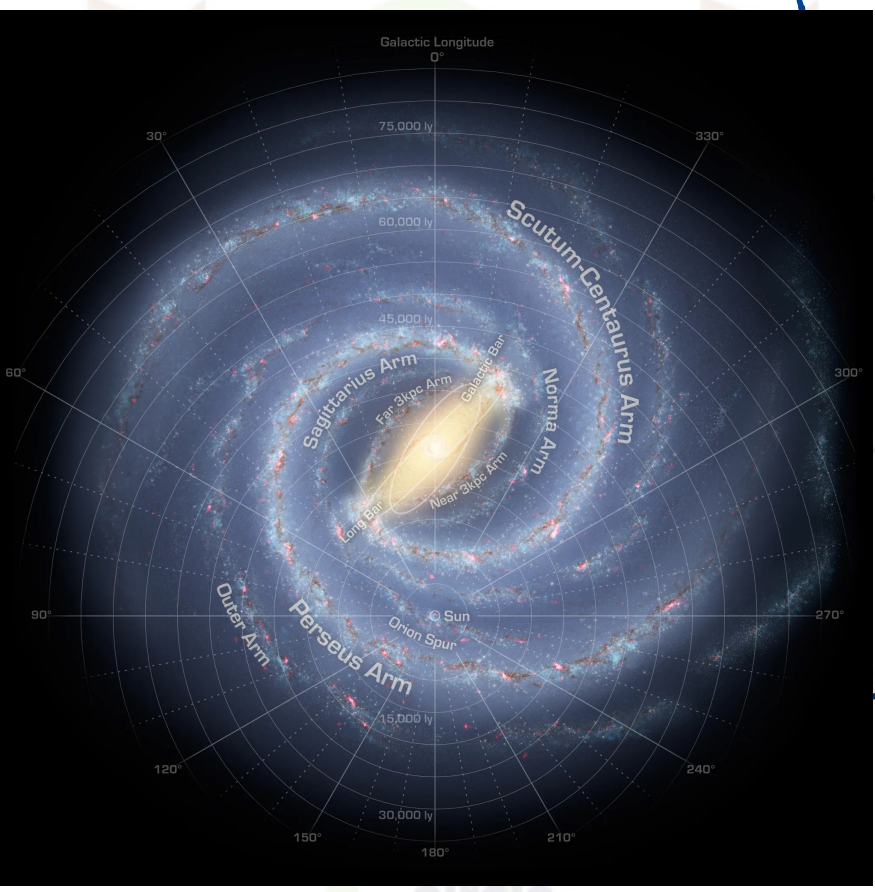
Space Physics

The Sun as a Star

The Milky Way

- Galaxies are made up of billions of stars
- The Universe is made up of many different galaxies.
- The Sun is one of the billions of stars in a galaxy called the Milky Way.
- Other stars in the Milky Way galaxy are much further away from Earth than the Sun is from earth.
- Some of these stars also have planets which orbit them.

Our Place in Space



This image is an artists concept based on scientific data.
The data is gathered from telescopes, simulations and models.

Our Solar System is just one out of potentially billions in our galactic neighbourhood, Milkyway. These are estimated to be more than 100 billion galaxies in the entire universe.

Astronomical Distances

Light Year

Distance travelled by light in one year.

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

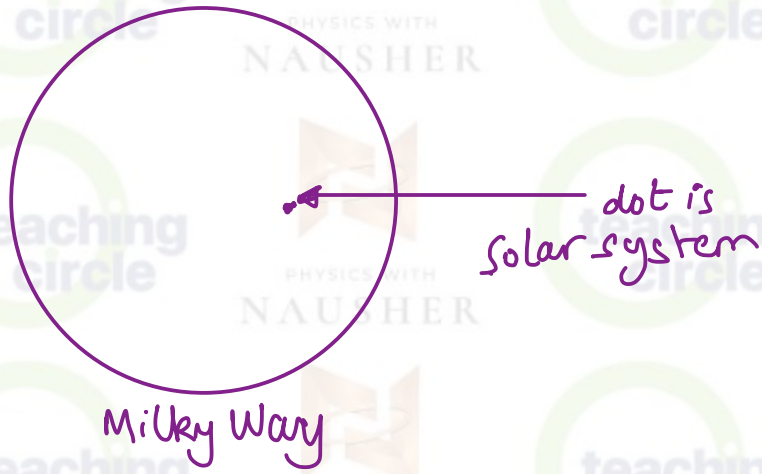
$$\text{distance} = \text{speed} \times \text{time}$$

$$= 3.0 \times 10^8 \times 365 \times 24 \times 3600$$

$$\boxed{1 \text{ Ly} = 9.5 \times 10^{15} \text{ m}}$$

Note: diameter of solar system: 1.5 ly

diameter of Milky way: 100,000 ly

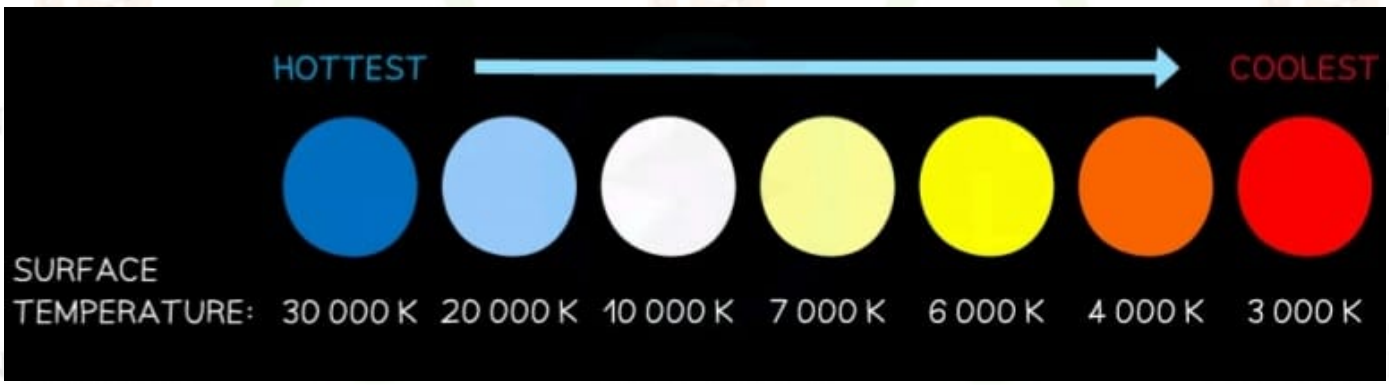


The Sun

- The Sun lies at the centre of the Solar System.
- The Sun is a **star** which makes up over 99% of the mass of the solar system.
- The fact that most of the mass of the Solar System is concentrated in the Sun is the reason the smaller **planets orbit the Sun**
- The planets are kept in orbit due to gravitational pull of Sun
- The Sun is a **medium-sized star** consisting of mainly **hydrogen** and **helium**.
- It radiates most of its energy in the **infrared, visible and ultraviolet** regions of the electromagnetic spectrum.
- Stars are powered by nuclear reactions (fusion) that release energy.

- Stars come in a wide range of sizes and colours, from yellow stars to red dwarfs, from blue giants to red super-giants.
  - These can be classified according to their colour.
- Warm objects emit infrared and extremely hot objects emit visible light as well.
  - Therefore, the colour they emit depends on how hot they are.
- A star's colour is related to its surface temperature.
  - A red star is the coolest (at around 3000K)
  - A blue star is the hottest (at around 30,000K)

Temperature and Colour of Stars



The colour of a star correlates to its temperature.

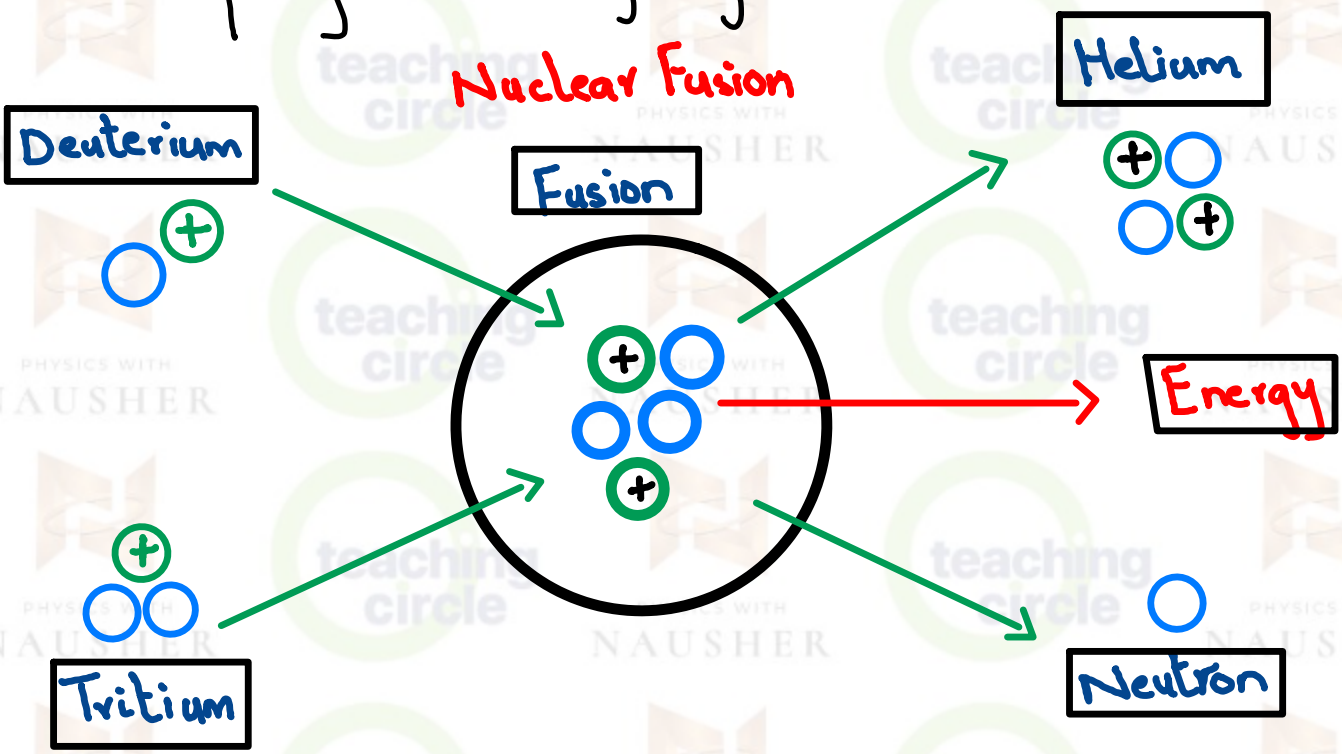
Nuclear Fusion in Stars

- In the centre of a stable star, hydrogen atoms undergo **nuclear fusion** to form helium
- The equation for the reaction is shown here:-

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

- The equation shows $^{2}_{1}H$ (deuterium) and $^{3}_{1}H$ (tritium) which are both isotopes of hydrogen
  - They can be formed through other fusion reactions in the star.

- A huge amount of energy is released in the reaction.
- This provides a pressure that prevents the star from collapsing under its gravity.



- Above diagram shows the fusion of deuterium and tritium to form helium with the release of energy.

Practise Time

Q) An example of a hydrogen fusion reaction which takes place in stars is shown here.

$$^{2}_{1}H + ^{1}_{1}H \rightarrow ^{3}_{2}He$$

Which of the following is a valid reason as to why hydrogen fusion is not currently possible on Earth?

A) Hydrogen fusion produces dangerous radioactive waste

B) Hydrogen nuclei require very high temperatures to fuse together

C) Hydrogen is a rare element that would be difficult to get large amounts of

D) Hydrogen fusion doesnot produce enough energy to be commercially viable.

Answer : B

- Hydrogen nuclei have positive charges
- So two hydrogen nuclei would have a repulsive force between them.
- High temperatures are required to give nuclei enough energy to overcome the repulsive force.
- The answer is not A because the product of the hydrogen fusion shown in the reaction is helium, and helium is inert gas.

- The answer is not C because hydrogen is a very abundant element.
  - It is the most common element in the universe.
- The answer is not D because hydrogen fusion would produce a huge amount of energy.

Q) What is the nuclear reaction that powers the Sun?

A) the fission of hydrogen into helium

B) the fission of helium into hydrogen

c) the fusion of hydrogen into helium

D) the fusion of helium into hydrogen

Correct Answer: C

Q) Nuclear fusion is one source of energy.

What is nuclear fusion?

A) the decay of a radioactive nucleus

B) the joining together of two nuclei to make a larger nucleus

C) the melting of an unstable nucleus

D) the splitting of a nucleus into two lighter nuclei

Correct answer: B

STARS

Star Formation: Supernova → causes nebula to collapse → formation of a proto star → Accretion of nebula → Main sequence star

1. Nebula

All stars form from a giant interstellar cloud of hydrogen gas and dust called a nebula.

https://www.youtube.com/watch?v=4kJUsNmwwDE

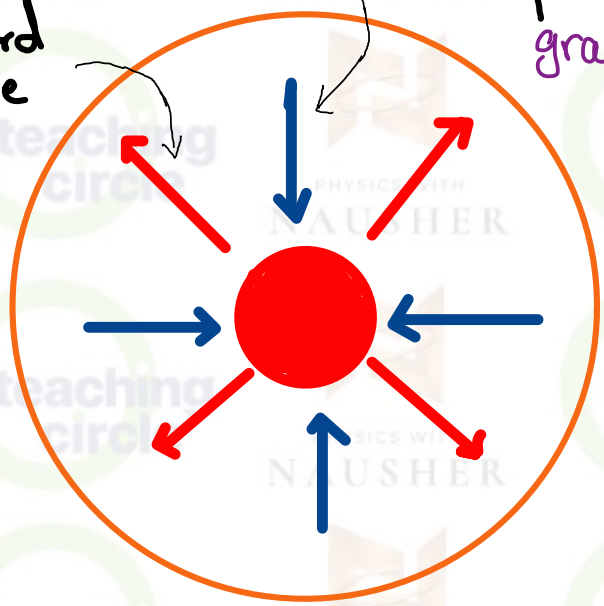
2. Protostar

- The force of gravity within a nebula pulls the particles closer together until a hot ball of gas forms, this is known as protostar.
- As the particles are pulled closer together the density of protostar will increase which will result in more frequent collisions between particles which causes the temperature to increase.

3- Main Sequence Star

- Once the protostar becomes hot enough, nuclear fusion reactions occur within its core.
- The hydrogen will fuse to form helium nuclei.
- Every fusion reaction releases heat (and light) energy which keeps the core hot.
- Once a star initiates fusion, it is known as a main sequence star.
- During the main sequence, the star is in equilibrium and said to be stable.
- The inward force due to gravity is equal to outward pressure force from the fusion reactions.

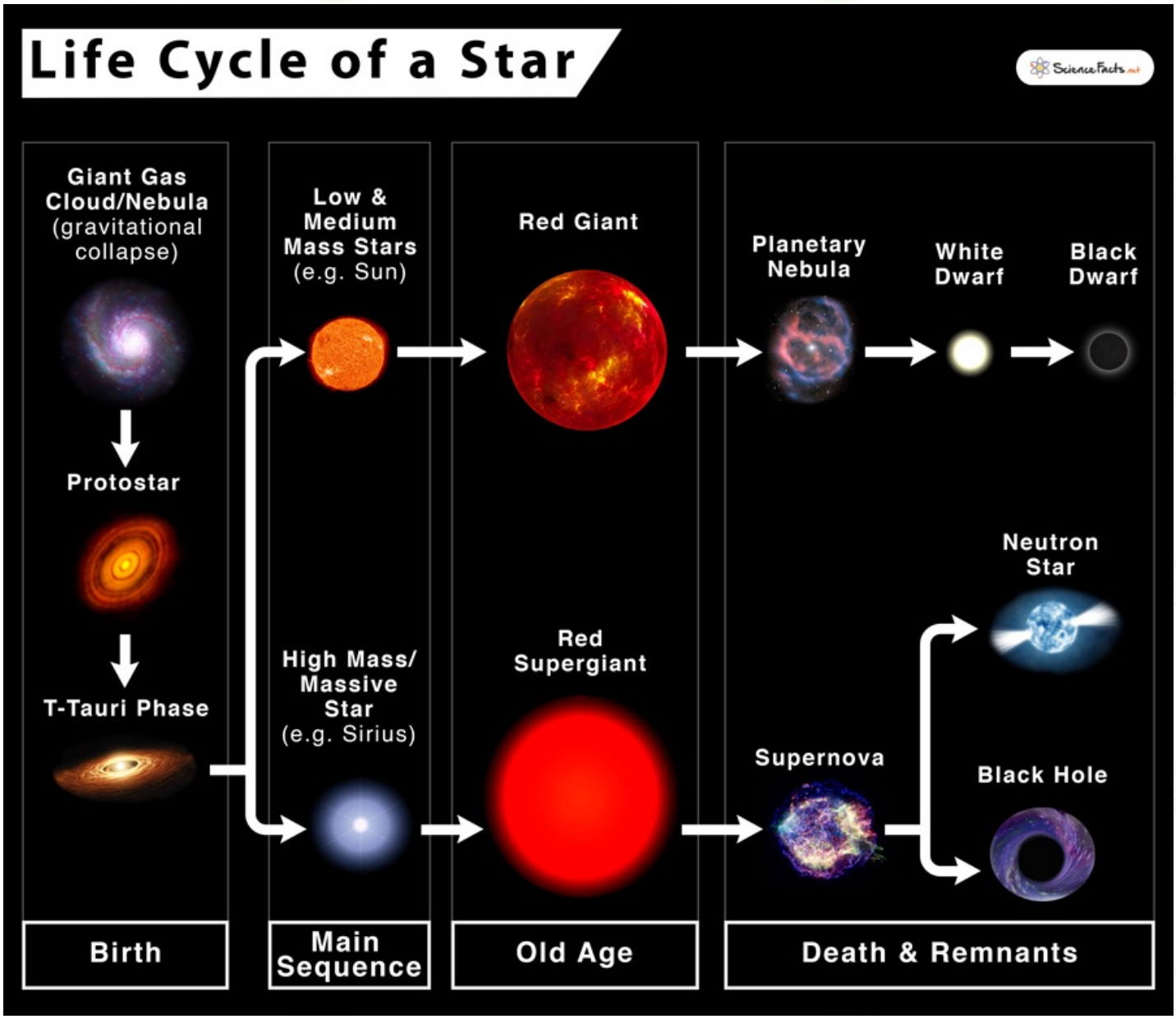
Equilibrium in a Star



The outwards and inwards forces within a star are in equilibrium. The centre red circle represents the star's core and orange circle represents the star's outer layers.

- Once a protostar is formed, the life cycle will depend on its mass.

Summary of Life Cycles of Stars

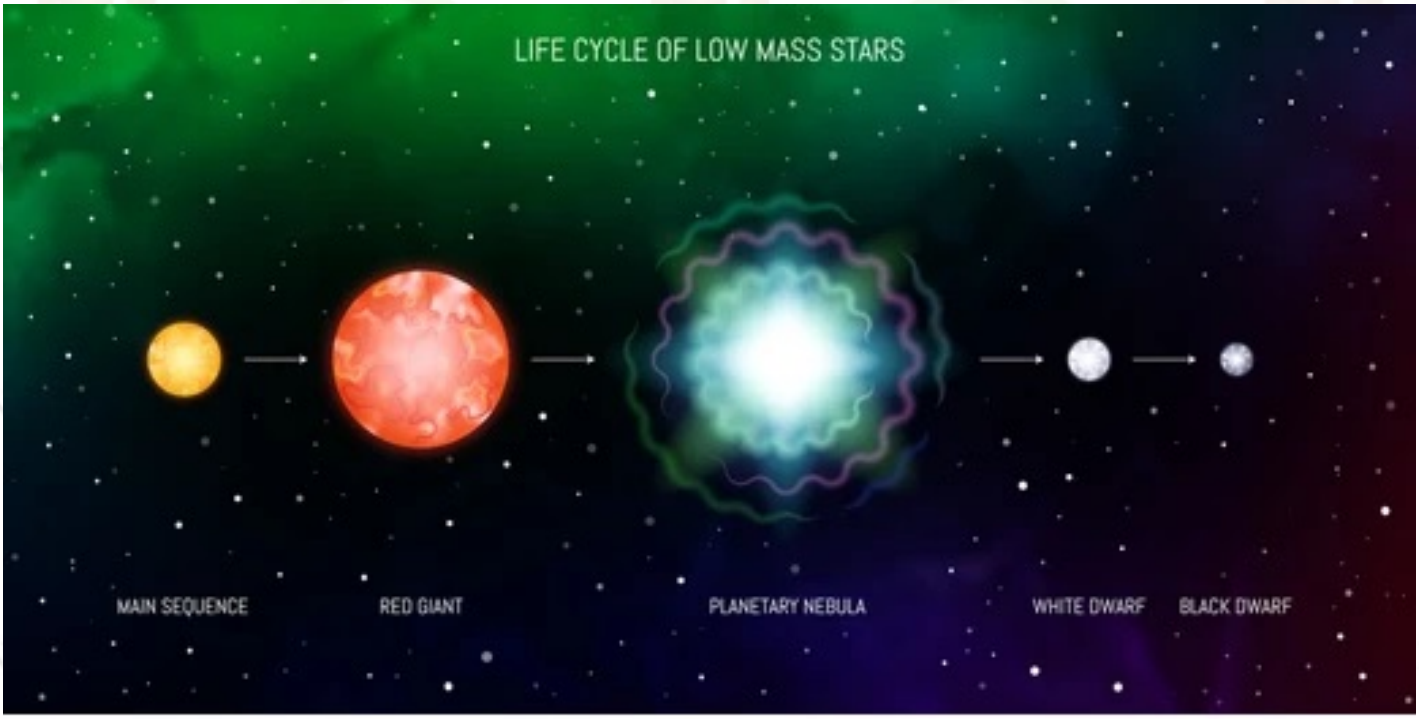


Flow diagram showing the life cycle of a star which is the same size as the Sun (solar mass) and the life cycle of star which is massive than the sun.

Life Cycle of Low Mass Stars

- A low-mass star will go through the following stages

Life Cycle of a Low-Mass Star



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A low-mass star will complete its lifecycle as a red giant, a planetary nebula and eventually a white dwarf.

4. Red Giant

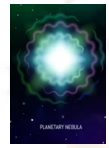
- After several billion years the hydrogen causing the fusion reactions in the star will begin to run out.
- Once this happens, the fusion reactions in the core will start to die down.

- This causes the core to shrink and heat up.
  - The core will shrink because the inward force due to gravity will become greater than the outward force due to pressure of the expanding gases as the fusion dies down.

inward forces > outward forces, (core contraction)

- A new series of reactions will occur around the core, for example, helium nuclei will undergo fusion to form beryllium. (Helium fusion)
- These reactions will cause the outer part of the star to expand and cool (red color)
- A low-mass star that is upto 8 times the mass of the Sun or smaller will become a red giant.
  - It is red because outer surface starts to cool.

5. Planetary Nebula



- Once this second stage of fusion reactions have finished, the star will become unstable and eject the outer layer of dust and gas.

- The layer of dust and gas which is ejected is called a planetary nebula.

6. White Dwarf

- The core which is left behind will collapse completely due to the pull of gravity, and the star will become a white dwarf.
- The white dwarf will be cooling down and as a result, the amount of energy it emits will decrease. No more fusion

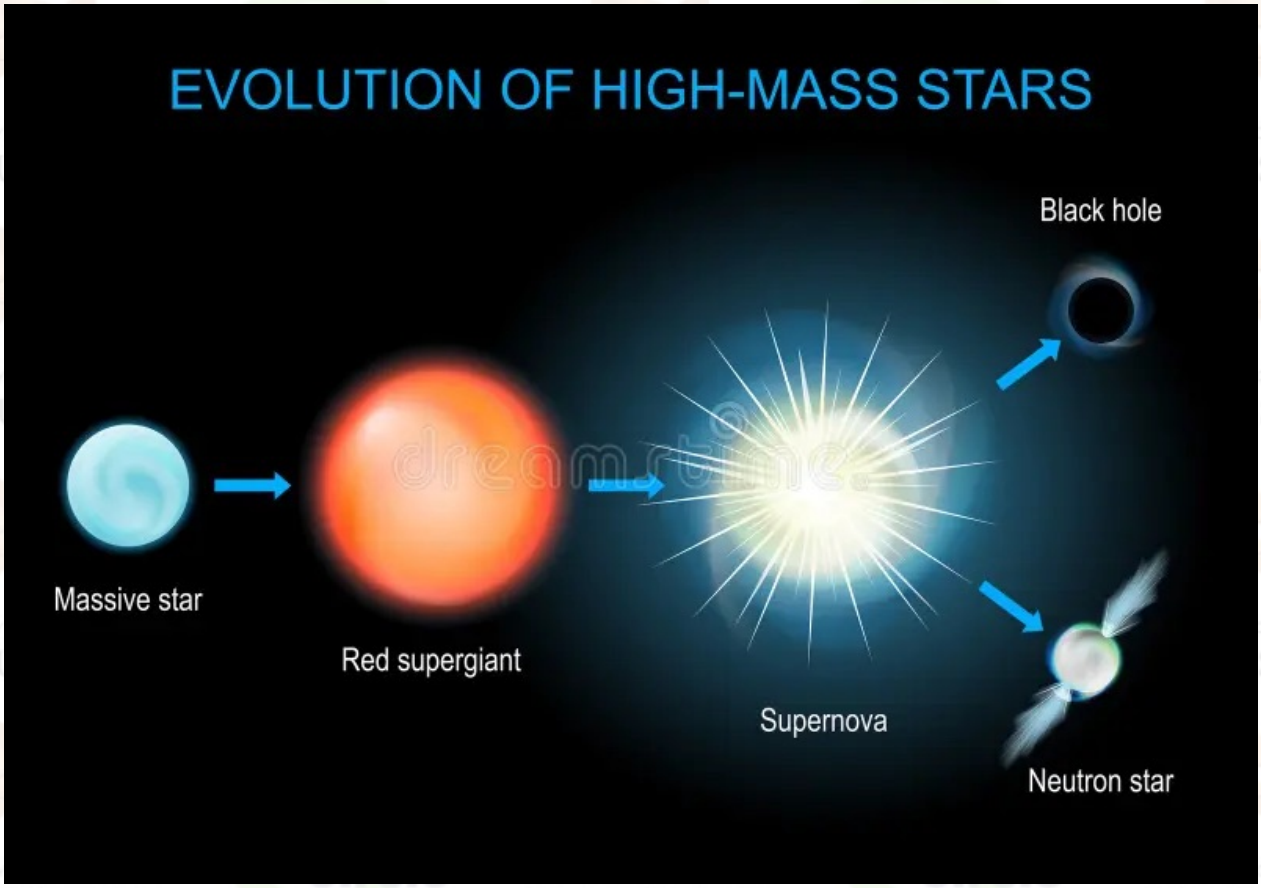
7. Black Dwarf (Hypothetical)

- Once the star has lost a significant amount of energy it becomes a black dwarf.
- it will continue to cool until it eventually disappears from sight.
- represents a star that has faded completely.

Life Cycle of High Mass Stars

- A high-mass star will go through the following stages

Life Cycle of a High-Mass Star



A high-mass star will complete its lifecycle as a red supergiant, a supernova and then either a neutron star or a black hole.

4. Red Supergiant

- After several million years, the hydrogen causing the fusion reactions in the star will begin to run out.

inward pull of gravity > outward pressure (core contraction)

- A high-mass star (one more than 8 times the mass of the Sun) will become a red supergiant.

- Similar to a low-mass star, the fusion reactions in the core will start to die down.

- The core will go through a series of periods of shrinking and heating up. However because a red supergiant is much more massive, its core can reach very high temperatures and pressures.

- This time, fusion reactions will form elements all the way up to iron. [Fusion goes beyond Helium]
e.g Helium, Carbon, oxygen, silicon.... iron

- Fusion reactions **cannot continue** once iron is formed. because fusing iron requires more energy than it releases.

5. **Supernova**

- An iron core is formed, inward forces become very strong. Once the fusion reactions inside the red supergiant cannot continue, the core of star will **collapse** suddenly and cause a gigantic explosion.

- This is called a supernova.

DEPENDING ON THE MASS OF THE CORE

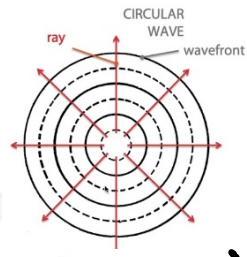
- At the centre of this explosion a dense body, called a neutron star will form.
- The outer remnants of the star will be ejected into space during supernova explosion, forming new clouds of dust and gas (nebula)
- The nebula from a supernova may form new stars with orbiting planets.
- The heaviest elements (elements heavier than iron) are formed during a supernova and are ejected into space.

6. Neutron Star (or Black Hole)

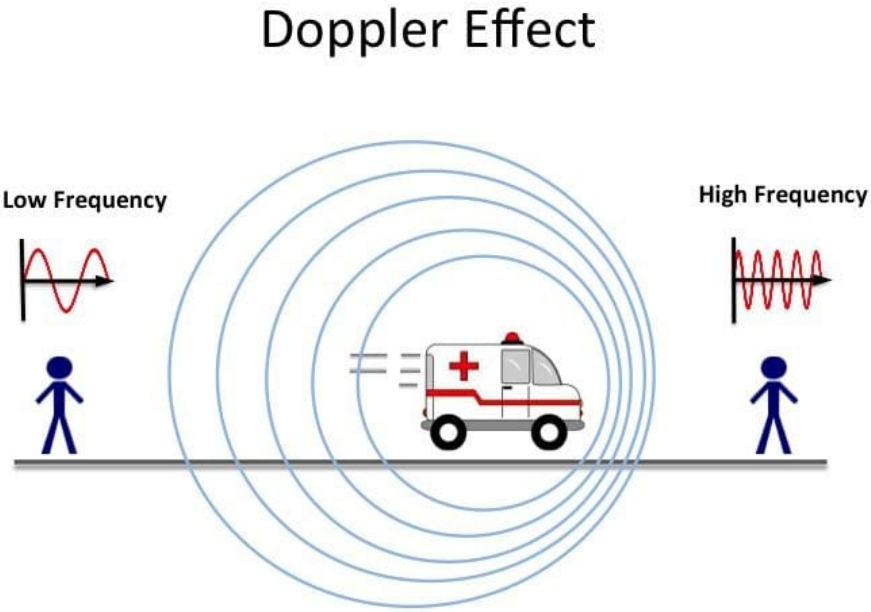
- In the case of the biggest stars, the neutron star that forms at the centre will continue to collapse under the force of gravity until it form a black hole.

- A black hole is an extremely dense point in space that not even light can escape.
- It has extreme gravitational properties.

Doppler effect



- Usually, when an object emit waves, the wavefronts spread out symmetrically
- if the wave source moves, the waves can become squashed together or stretched out.



- A moving object will cause the wavelength and frequency of the waves to change:
  - The wavelength of the waves in front of the source decreases and frequency increases.
  - The wavelength behind the source increases and the frequency decreases.
  - This effect is known as Doppler effect.

- The Doppler effect also affects light.
  - if an object moves away from an observer the wavelength of light increases
  - This is known as redshift as light moves towards the red end of spectrum.

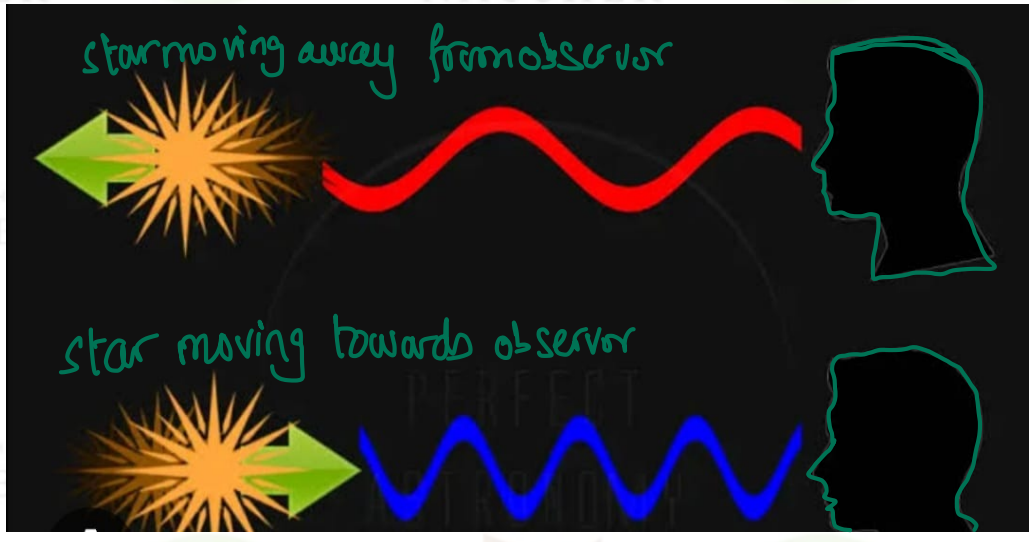
VIBGYOR

min wavelength ← wavelength increases → max wavelength

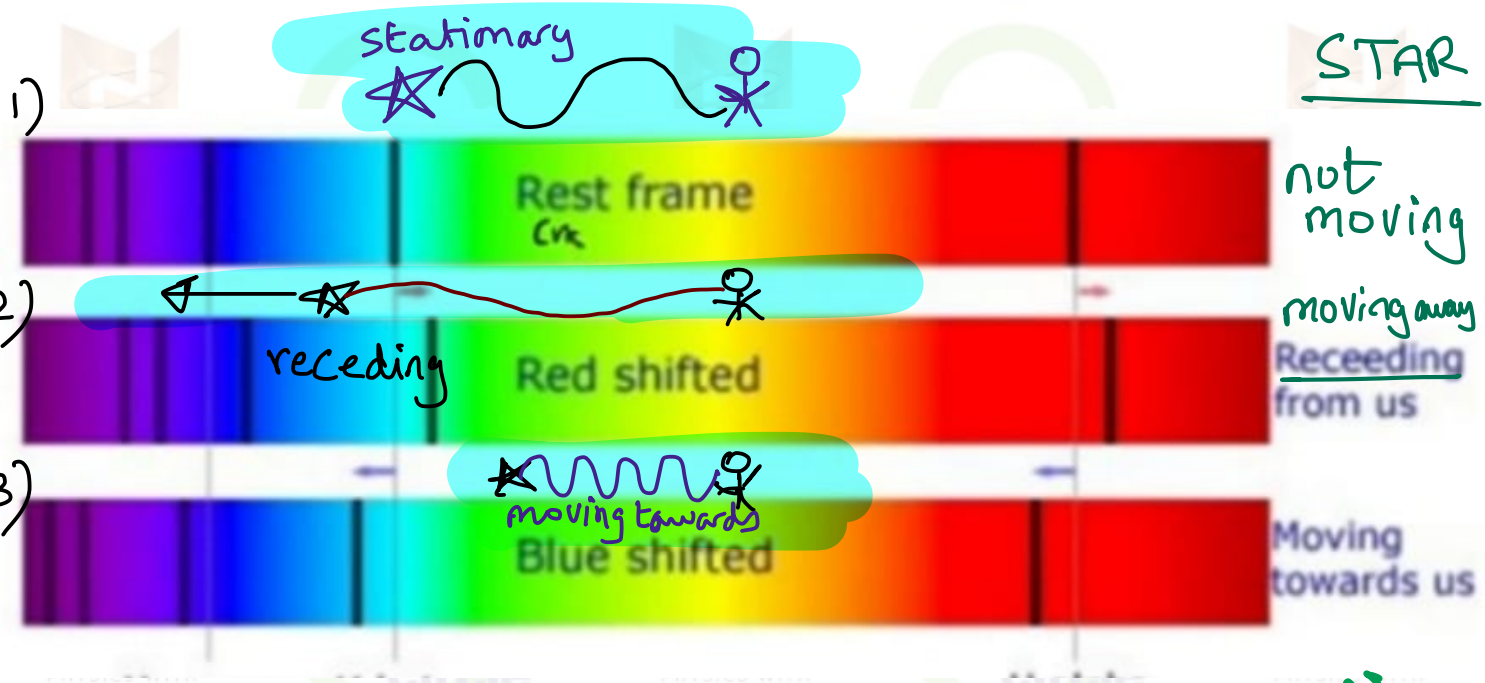
- **Redshift:**

An increase in observed wavelength of electromagnetic radiation emitted from receding stars and galaxies.

RED SHIFT AND BLUE SHIFT



Light source moving towards the observer will be blue shifted and Light source moving away from observer will be Red shifted.



STAR

1) not moving

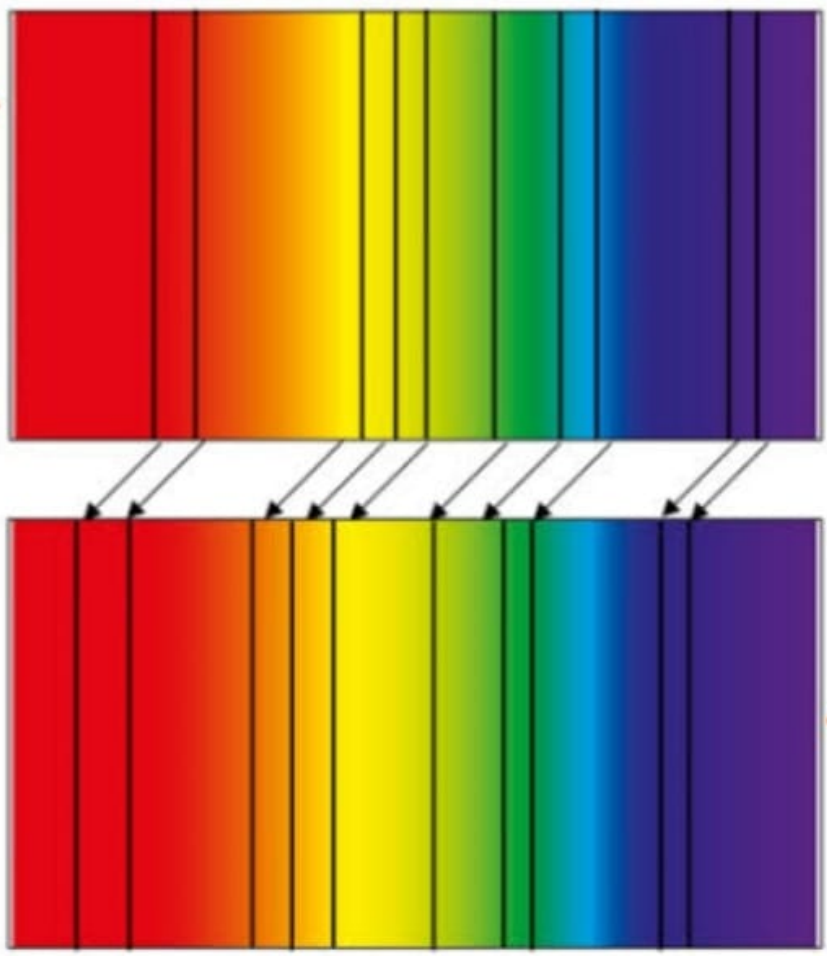
2) moving away
Receeding from us

3) Moving towards us

Above spectrum shows Doppler shift, (Redshift)

- Light emitted from distant galaxies appears red-shifted when compared with light emitted on Earth as shown below:

An absorption spectrum showing dark lines measured on Earth.



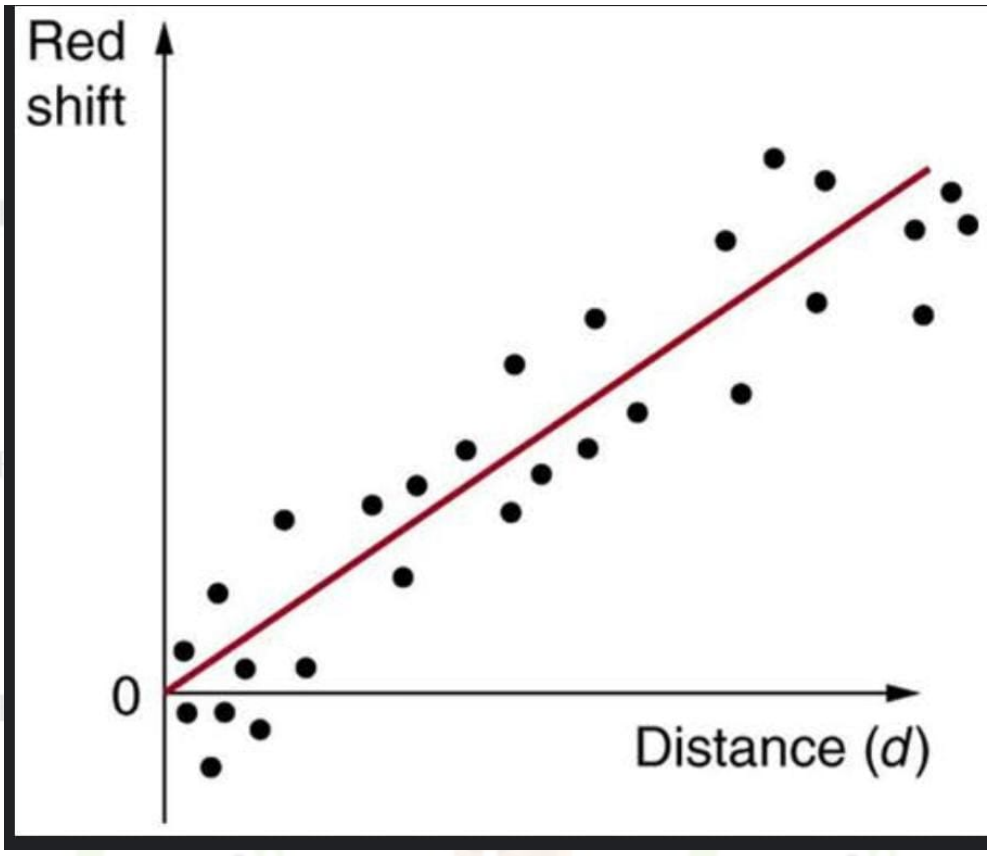
This is the same absorption spectrum which measured from light from a distant galaxy

Above diagram shows that the light coming to us from distant galaxy is redshifted.

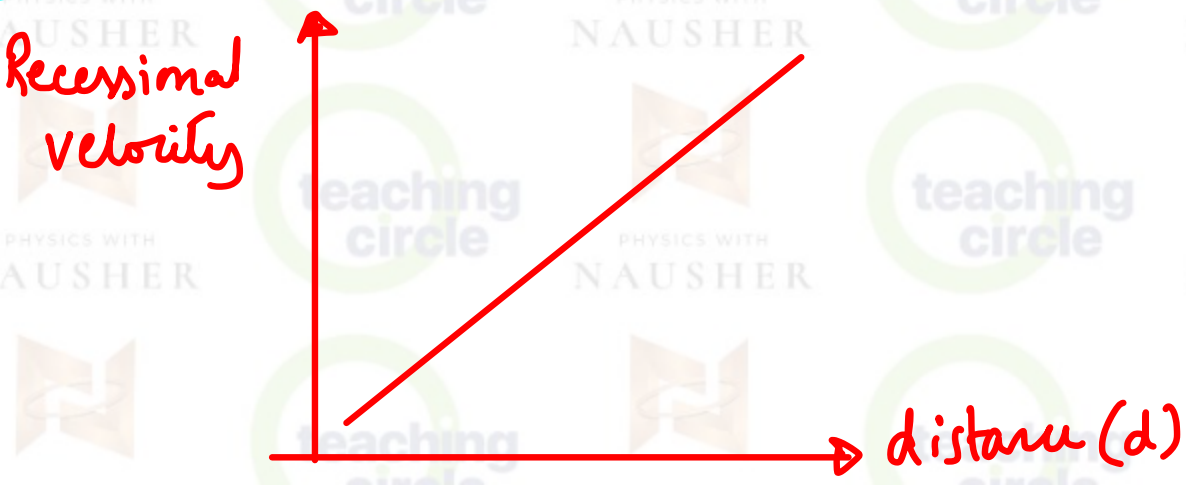
- The lines on spectrum are shifted towards red end.

- This indicates that the galaxies are moving away from us.
- If galaxies are moving away from us this means universe is expanding.
- The observation of redshift from distant galaxies supports the Big Bang theory

Relationship of Redshift with distance from observor (earth)



- The graph above shows that as distance from the observor (earth) increases, the red shift increases.
- The reason for the greater red shift can be found from Hubble's Law.



As the distance from the earth increases, the speed at which galaxies and stars move away (recessional speed) also increases.

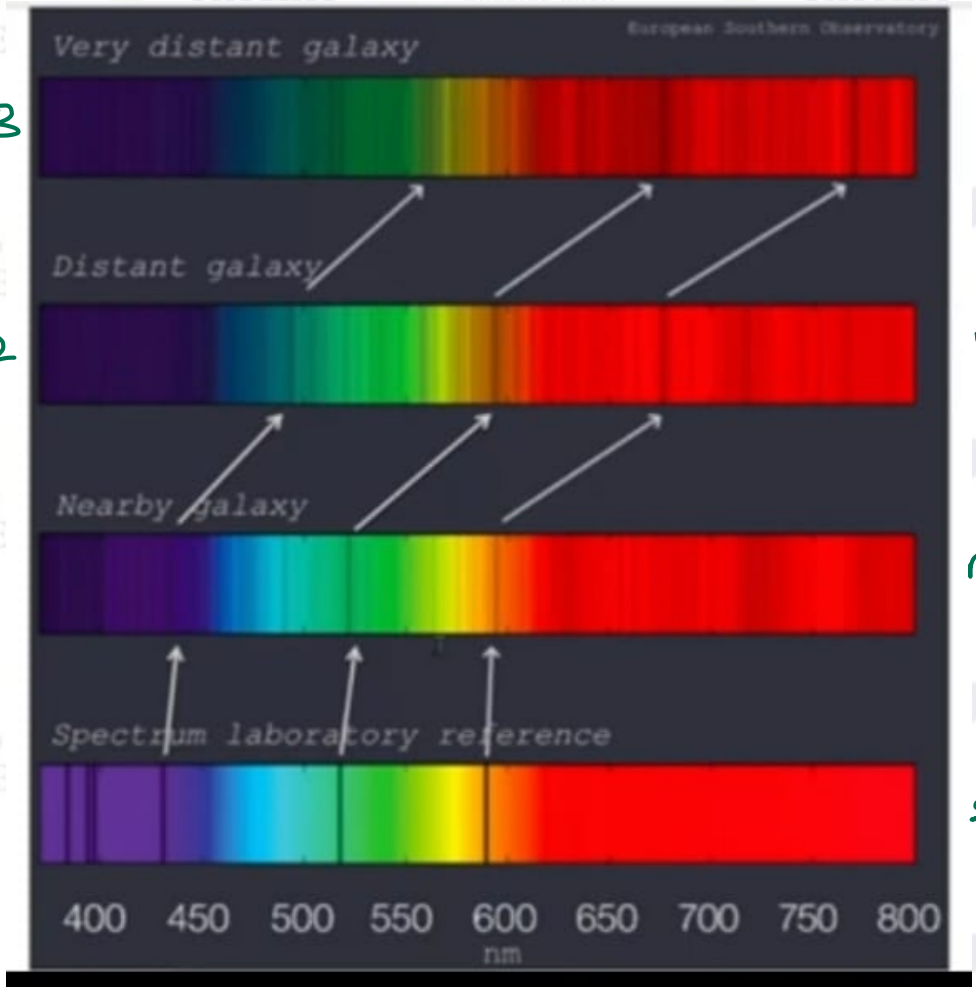
So,

greater the distance from observer (earth) → greater the recessional speed → greater the red shift

$d \propto v \propto \Delta\lambda$

(d = distance from observer; v = recessional velocity; $\Delta\lambda$ = change in wavelength)

Q. Look at the diagram below and suggest which galaxy has the greatest speed and in what direction do they move.



. Spectrum above shows that greater the distance to galaxy, greater the red shift, which means further away a galaxy is, the faster it is moving away from us.

Note:

. Space is expanding, this causes galaxies to move away from each other, leading to the observed redshift.

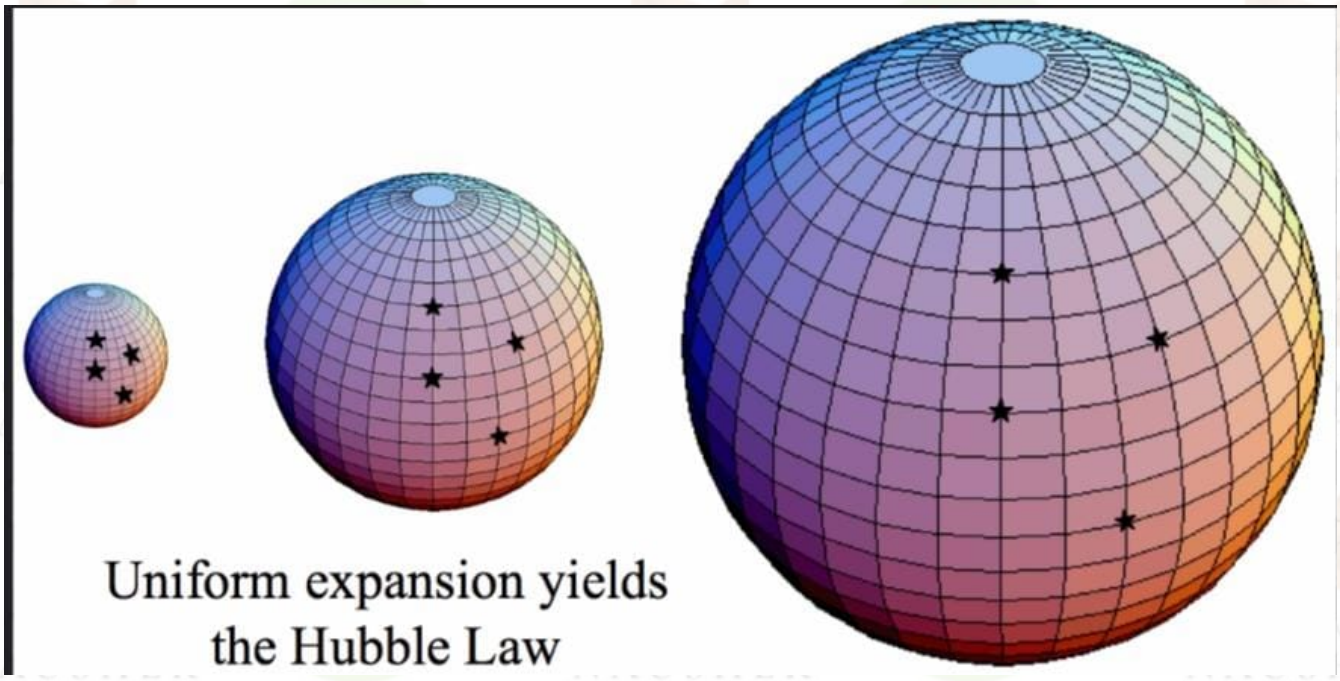
. The greater the red shift, the faster a galaxy is receding, the greater its distance from observer (us), which proves space is expanding.

. This expansion is the result of a Big Bang which occured 14 billion years ago.

The Big Bang

- Going backwards in time, the Universe began from a very small region that was extremely hot and dense.
- Then there was a giant explosion, which is known as the Big Bang
- This caused the universe to expand from a single point, cooling as it does so, to form the universe today.
- Each point expands away from the others
  - This is seen from galaxies moving away from each other, and further away they are, faster they move.
- View the figure below

- Redshift in the light from distant galaxies is evidence that the universe is expanding and supports the BigBang theory.
  - As a result of initial explosion, the universe continue to expand.



All galaxies are moving away from each other indicating that the universe is expanding.

Are the galaxies physically moving through space

or

is space expanding between them

- An analogy of this is points drawn on a balloon where balloon represents the space and points as galaxies.
- When the balloon is deflated, all the points are close together and an equal distance apart.
- As the balloon expands, all the points become further apart by same amount.
- This is because the space has itself expanded b/w the galaxies.

8 Fig. 8.1 is a picture of a nebula formed from a supernova.

Fig. 8.1

(a) State what is meant by 'a supernova'.

explosion of a red giant

.....

..... [2]

(b) Describe how a protostar forms inside a nebula.

cloud of dust and gas come together due to gravitational attraction.

.....

..... [2]

(c) Our Sun is in a circular orbit around a black hole at the centre of our galaxy.

(i) State the name of the galaxy that contains our Sun.

Milky way ..... [1]

(ii) State what is meant by a light-year.

distance travelled by light in one year ..... [1]

(iii) The time taken for one complete orbit of our Sun around the black hole is 7.3×10^{15} s.

The distance from our Sun to the black hole is 26000 light-years.

1 year = 3.2×10^{7} s speed of light = 3.0×10^{8} m/s

Calculate the speed of our Sun as it orbits the black hole.

Show your working and give your answer in m/s.

$1ly = v \times t$

$= 3 \times 10^{8} \times 3.2 \times 10^{7}$

$$v = \frac{2\pi r}{t} = \frac{2\pi \times 26000 \times 3 \times 10^{8} \times 3.2 \times 10^{7}}{7.3 \times 10^{15}}$$

speed = 2.1×10^{5} m/s [3]

[Total: 9]

Question	Answer	Marks
8(a)	explosion	C1
	explosion of a red giant / massive star (at the end of its life cycle)	A1
8(b)	clouds of dust / gas come together / collapse	B1
	due to gravitational attraction **or** resulting in an increase in temperature	B1
8(c)(i)	milky way	B1
8(c)(ii)	distance travelled by light in one year	B1

Question	Answer	Marks
8(c)(iii)	(speed =) distance / time **or** $2\pi R / T$ in any form	C1
	$2\pi \times 26\,000 \times 3 \times 10^8 \times 3.2 \times 10^7$ seen	C1
	210 000 (m / s)	A1

40 Four of the stages in the life cycle of a star, until it becomes a red giant, are shown.

W Inward force of gravitational attraction is balanced by an outward force from its centre. Main sequence

X Internal gravitational collapse produces an increase in temperature. Nebula → Protostar

Y It expands. Red giant

Z Most of the hydrogen has been converted to helium. shrink and heat up

In which order do these stages occur, starting with the earliest?

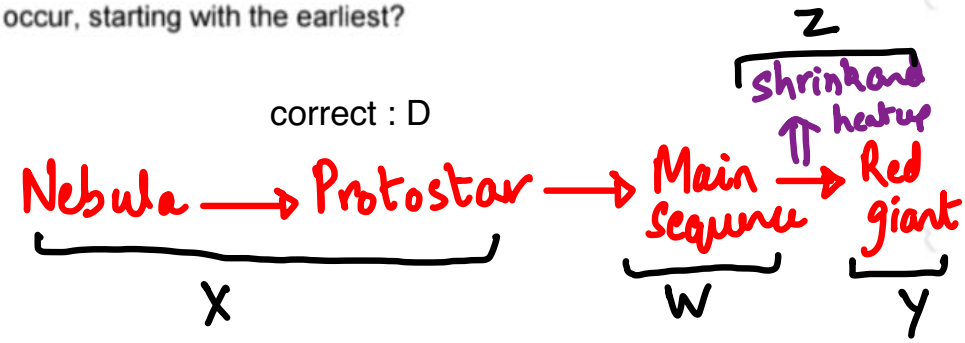
A W → X → Y → Z

B W → X → Z → Y

C X → W → Y → Z

D X → W → Z → Y

correct : D



10 (a) Astronomical distances are measured in light-years.

(i) State what is meant by 'a light-year'.

distance travelled by light in one year.

..... [1]

(ii) The Sun is one star in the Milky Way galaxy.

State the approximate diameter of the Milky Way galaxy.

diameter of Milky Way = 100,000 light-years [1]

(b) There are several stages in the life cycle of a star.

(i) Complete Fig. 10.1 to show the stages that a **massive** star goes through after it has used up most of the hydrogen at the centre of the star.

Use words from the following list:

nebula **neutron star** **protostar** **red giant** **supernova** **white dwarf**

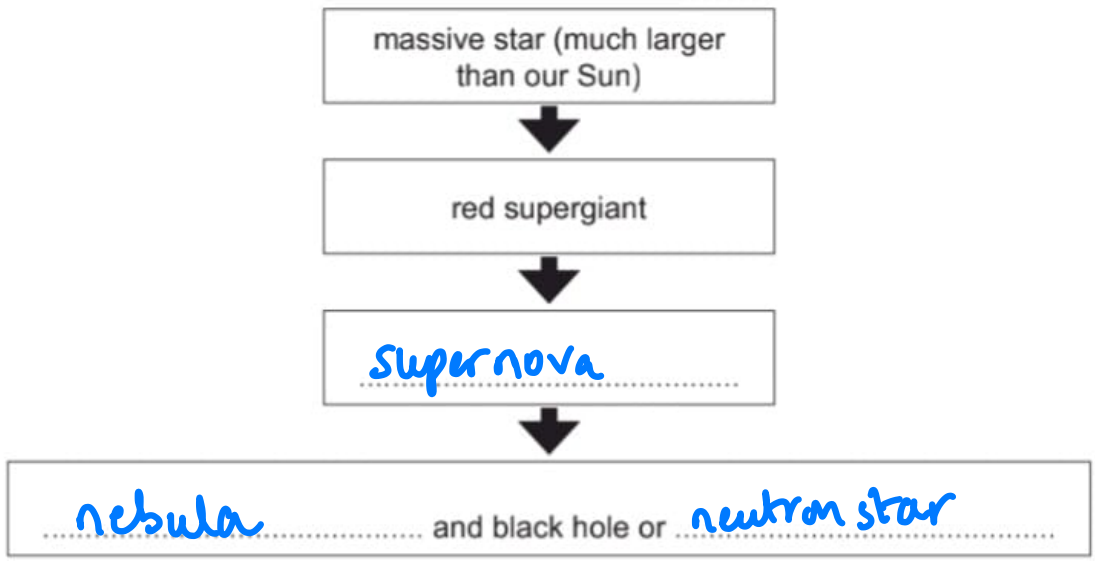


Fig. 10.1

[2]

(ii) State the stage in the life cycle of a star where heavy elements are formed.

heavier than iron

supernova.

..... [1]

Note: . Elements upto Fe-56 formed in the red giant stage

• In a supernova, the explosion creates extreme temperatures and pressures necessary to form elements heavier than iron e.g gold, platinum, uranium.

(c) Current scientific understanding is that the universe began 14 billion years ago in an event known as the Big Bang.

Explain **one** observation that supports the Big Bang Theory.

observation red shift in the light spectrum observed from distant galaxies.

explanation As distance increases, the recessional velocity of the galaxy increases. This greater velocity causes greater change in wavelength. The wavelength is longer. Going backwards in time, the galaxies were close together and the universe began from a point which was very hot and dense.

[4]

[Total: 9]

Question	Answer	Marks
10(a)(i)	distance travelled (in a vacuum) by light in one year	B1
10(a)(ii)	100 000	B1
10(b)(i)	supernova	B1
	nebula **and** neutron star	B1
10(b)(ii)	in a supernova	B1

Question	Answer	Marks
10(c)	**either** red shift / increase in (observed) wavelength / reduction in frequency mentioned **or** galaxies / stars moving away (from the Earth) / separating	B1
	further away (the galaxy / star) the greater its speed / greater red shift / greater increase in wavelength	B1
	going backwards in time / at start) stars or galaxies were close together **or** high density / dense	B1
	cosmic microwave background mentioned **or** universe expands	B1
	remnant heat / radiation / left over radiation / radiation from early universe observed now	B1
	radiation has red shifted / longer wavelengths / smaller frequency / become cooler **or** CMBR is uniform / observed in all directions	B1

Nebula

39 What is the first stage in the life cycle of stars?

A a black hole

B a cloud of gas and dust

C a red supergiant

D a supernova

B

increase in wavelength

40 What is the definition of redshift?

A the increase in observed frequency of light from galaxies that are moving away from the Earth

B the increase in observed wavelength of light from galaxies that are moving away from the Earth

C the light emitted by distant galaxies that is blue when it reaches the Earth

D the light reaching the Earth that is red when it is emitted by distant galaxies

B

closer

40 When observed on the Earth, the redshift of the light from galaxy X is smaller than the redshift of the light from galaxy Y.

greater redshift

Which galaxy is closer to the Earth and which galaxy is receding from the Earth faster?

	closer to the Earth	faster recession
A	X	X
B	X	Y
C	Y	X
D	Y	Y

B

For Y

redshift ↑, recessional velocity ↑