IGCSE/GCE O-LEVEL

Earth and the Solar System

By: Aamir Yasin
03355000077

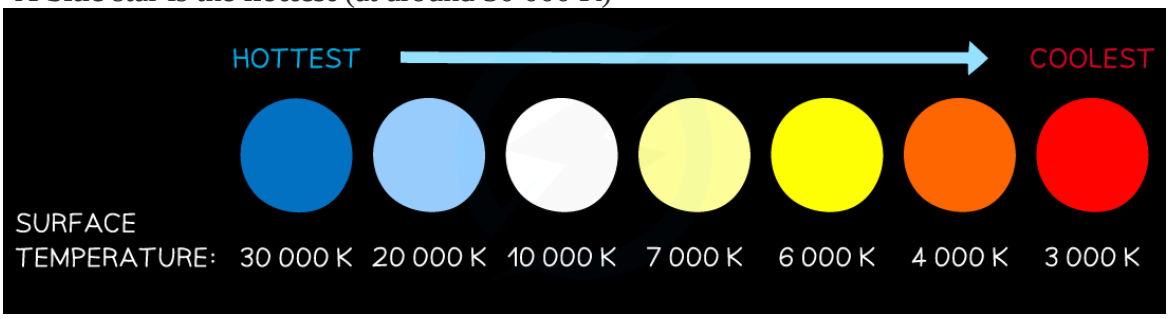
The Spectrum Academy
AAMIR YASIN
www.facebook.com/academyspectrum
www.instagram.com/thespectrumacademy

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 gravitational pull of the Sun on the planets keeps them in orbit
- 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

Our Sun

- Stars come in a wide range of sizes and colours, from yellow stars to red dwarfs, from blue giants to red supergiants
    - 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 3000 K)
    - A **blue** star is the **hottest** (at around 30 000 K)



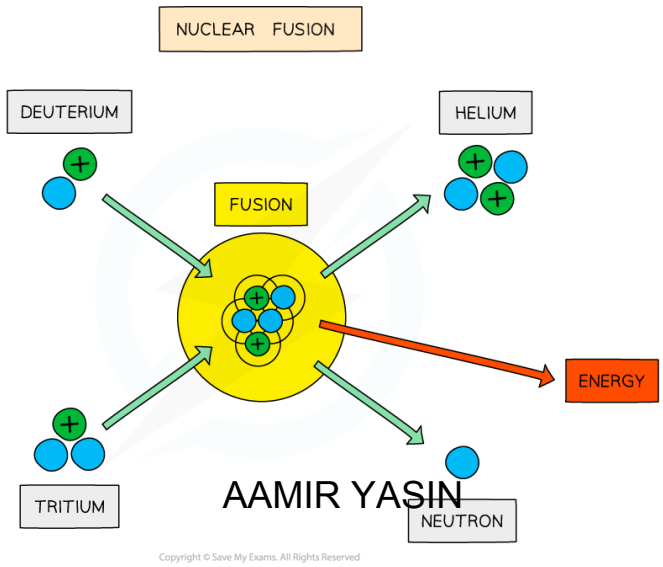
Nuclear Fusion in Stars

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

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

Deuterium and Tritium are both isotopes of hydrogen. They can be formed through other fusion reactions in the star

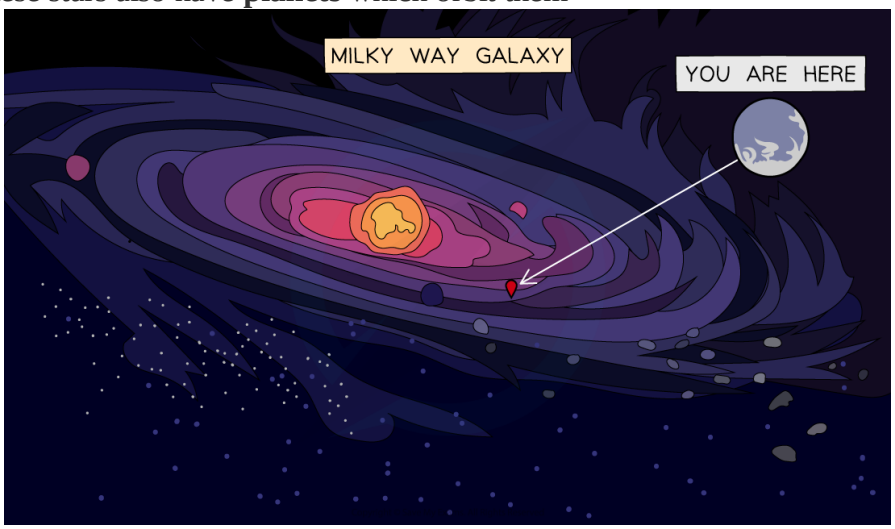
- A **huge** amount of energy is released in the reaction
- This provides a pressure that prevents the star from collapsing under its gravity



The fusion of deuterium and tritium to form helium with the release of energy

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 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
- Some of these stars also have **planets** which orbit them



Our solar system is just one out of potentially billions in our galactic neighbourhood, the Milky Way. There are estimated to be more than 100 billion galaxies in the entire universe

- **Astronomical distances** such as the distances between stars and galaxies, are so **large** that physicists use a special unit to measure them called the **light-year**

- One light-year is:
  The distance travelled by light through (the vacuum of) space in one year
- The speed of light is the **universal speed limit**, nothing can travel faster than the speed of light
- But over astronomical distances, light actually travels pretty slowly
- The **diameter of the Milky Way** is approximately **100 000 light-years**
  - This means that light would take 100 000 years to travel across it
- **One light year = 9.5×10^{12} km = 9.5×10^{15} m**

Life Cycle of Stars

1. Nebula

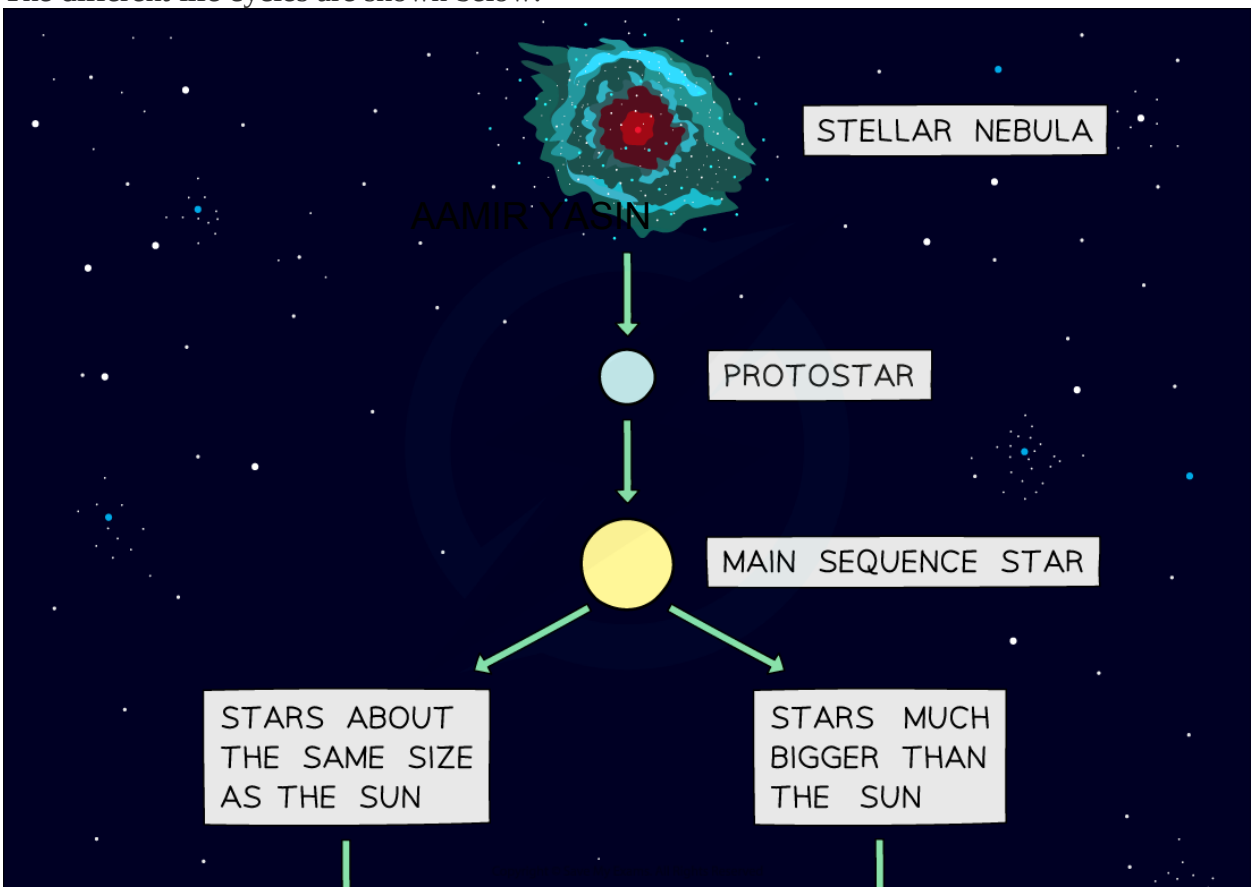
- All stars form from a giant interstellar cloud of **hydrogen gas** and **dust** called a **nebula**

2. Protostar

- The force of **gravity** within a nebula pulls the particles **closer together** until it forms a hot ball of gas, known as a **protostar**
- As the particles are pulled closer together the **density** of the protostar will **increase**
  - This will result in **more frequent collisions** between the 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** nuclei will fuse to form **helium** nuclei
  - Every fusion reaction releases **heat** (and light) energy which keeps the core hot
- Once a protostar is formed, its life cycle will depend on its **mass**
- The different life cycles are shown below:



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

- Once a star is born 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 the **outward pressure force** from the fusion reactions

4. Red Giant or Red Super 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 the pressure of the expanding gases as the fusion dies down
- A new series of reactions will then occur around the core, for example, **helium** nuclei will undergo **fusion** to form **beryllium**
- These reactions will cause the outer part of the star to **expand**
- A low-mass star that is up to 8 times the mass of **the Sun** or smaller will become a **red giant**
- A high-mass star that is more than 8 times the mass of **the Sun** will become a **red super giant**
    -
    - It is red because the **outer surface** starts to **cool**

5. For Red Giant Stars

Planetary Nebula

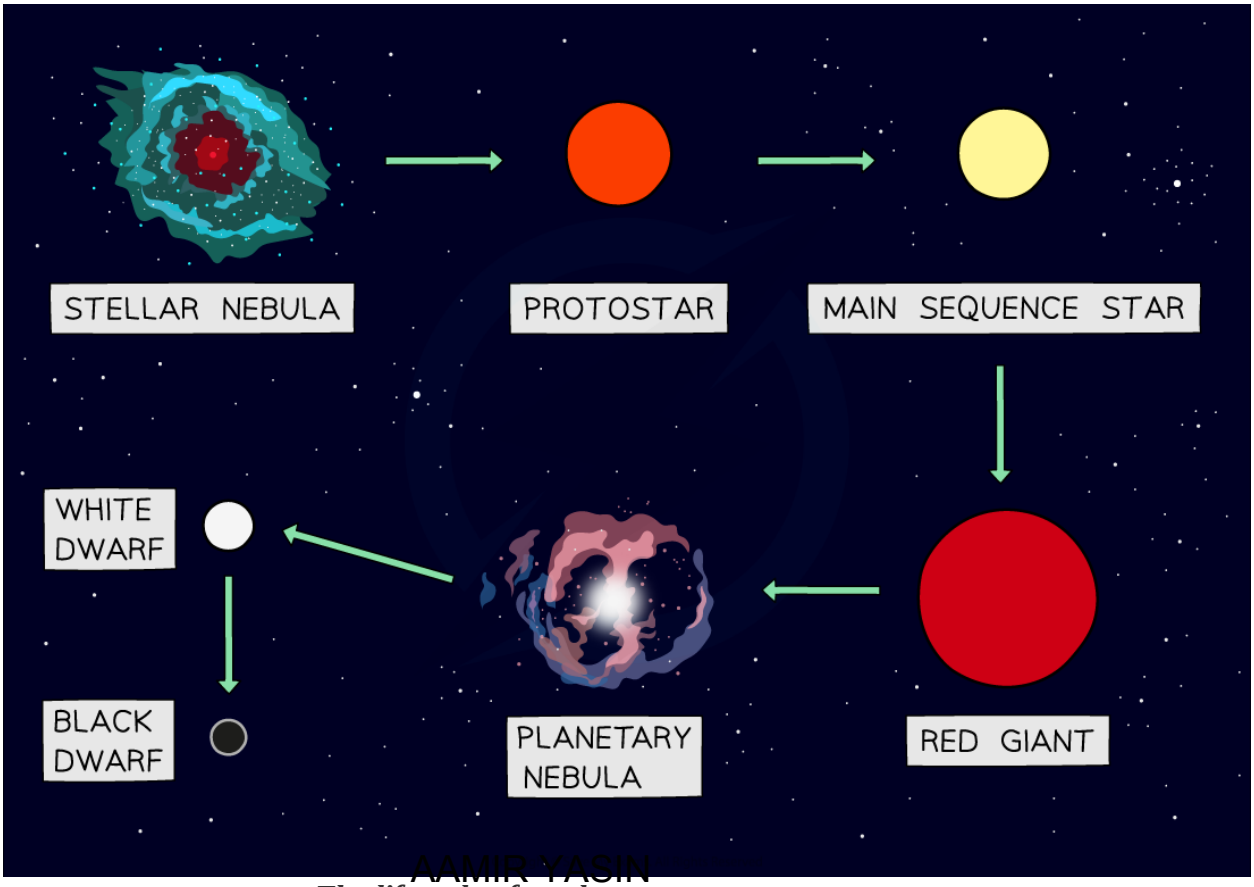
- Once this second stage of fusion reactions have finished, the star will become **unstable** and eject the outer layer of dust and gas
    - The layer of dust and gas which is ejected is called a **planetary nebula**

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**

Black Dwarf

- 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



The lifecycle of a solar mass star

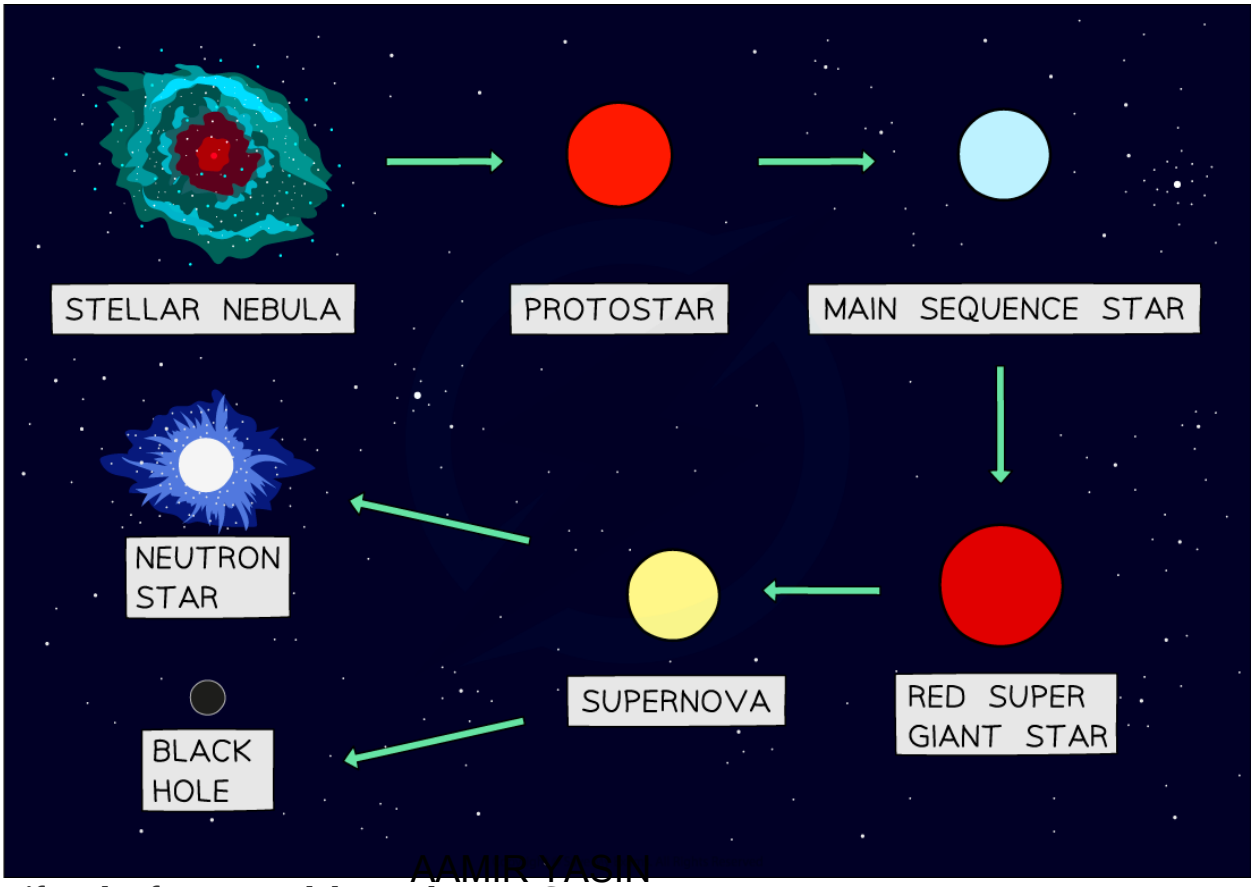
6. For Red Super Giants

Supernova

- Once the fusion reactions inside the red supergiant finally finish, the core of the star will **collapse suddenly** causing a **gigantic explosion**
  - This is called a **supernova**
- 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 the supernova explosion, forming a **planetary nebula**
  - The nebula from a supernova may form **new stars** with **orbiting planets**

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 forms a **black hole**
  - A black hole is an **extremely dense** point in space that not even **light** can escape from



Lifecycle of a star much larger than our Sun

Galaxies & Redshift

- Usually, when an object emits waves, the wavefronts spread out **symmetrically**
- If the wave source moves, the waves can become squashed together or stretched out

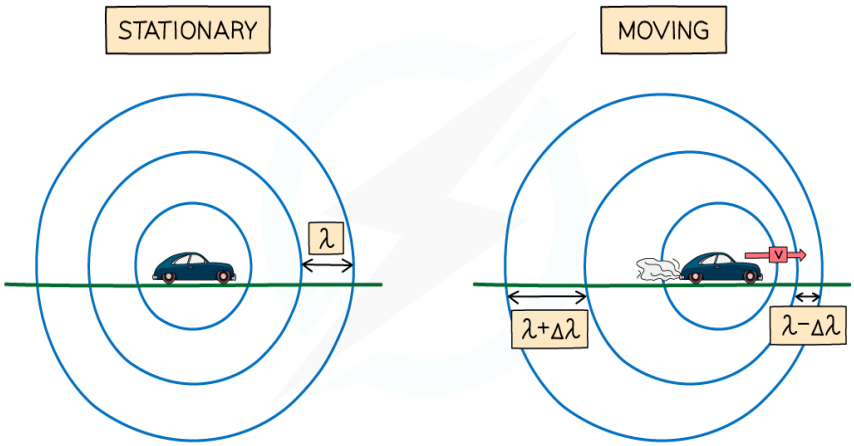
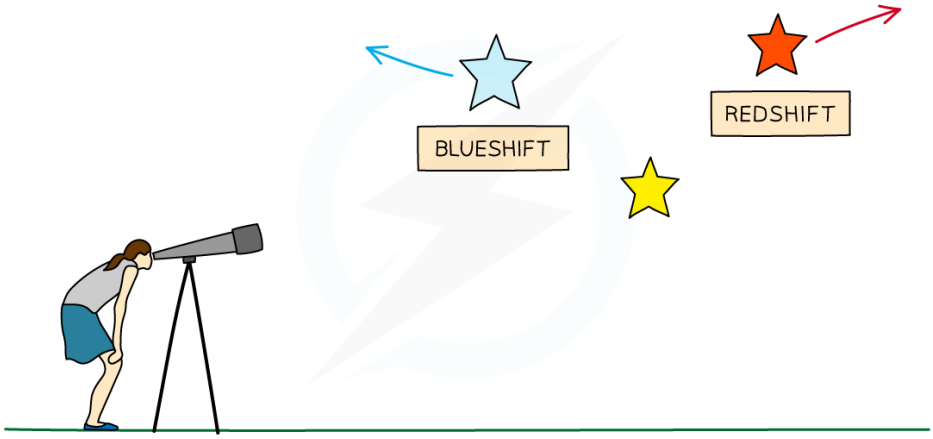


Diagram showing the wavefronts produced from a stationary object and a moving object

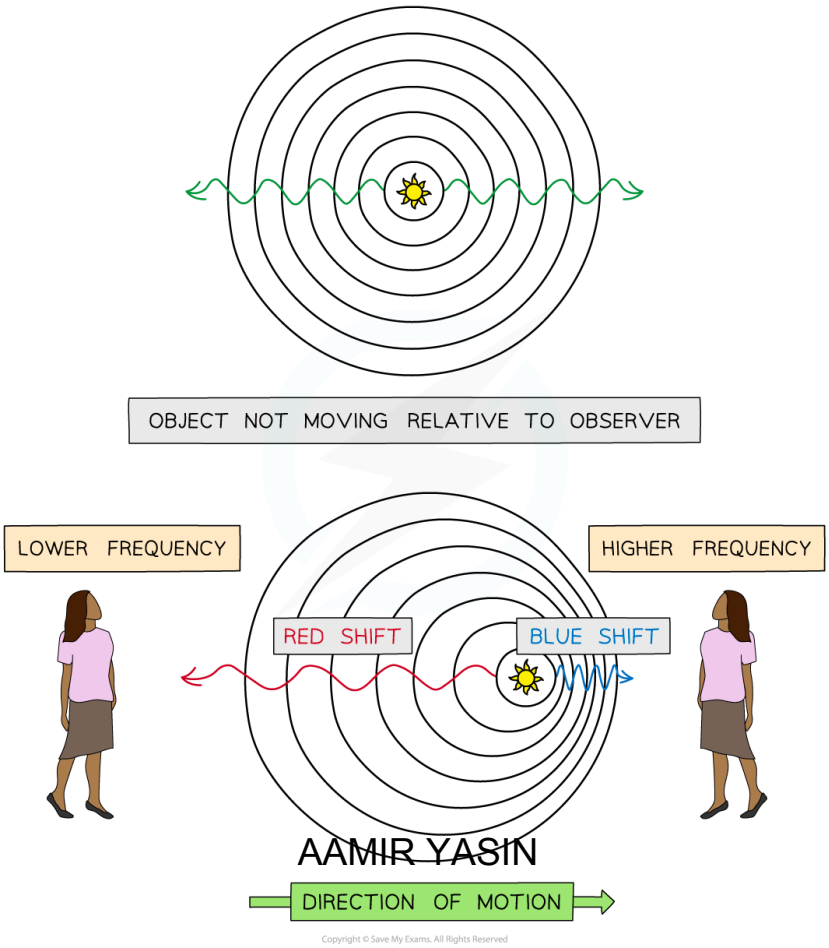
- A moving object will cause the **wavelength**, λ, (and frequency) of the waves to change:
  - The **wavelength** of the waves **in front** of the source **decreases** and the **frequency increases**
  - The wavelength **behind** the source **increases** and the **frequency decreases**
  - This effect is known as the **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 the light moves towards the red end of the spectrum
- Redshift is:

  An increase in the observed wavelength of electromagnet radiation emitted from receding stars and galaxies

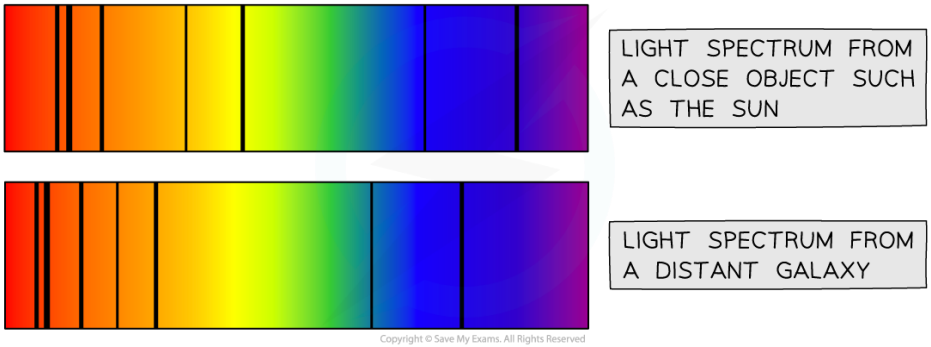


Light from a star that is moving towards an observer will be blueshifted and light from a star moving away from an observer will be redshifted



The observer behind observes a red shift

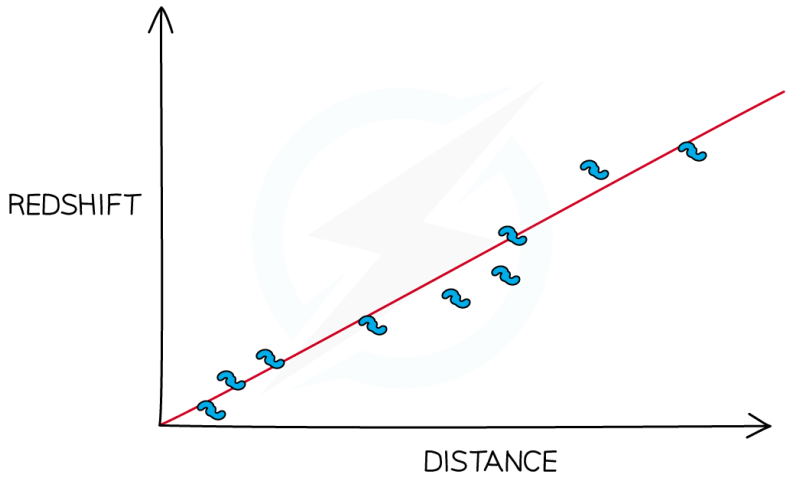
- The Milky Way is just one of **billions of galaxies** that make up the **Universe**
- Light emitted from **distant galaxies** appears **redshifted** when compared with light emitted on Earth
- The diagram below shows the **light** coming to us from a **close object**, such as the Sun, and the light coming to us from a **distant galaxy**



Comparing the light spectrum produced from the Sun and a distant galaxy

- The diagram also shows that the light coming to us from **distant galaxies** is **redshifted**
  - The lines on the spectrum are shifted towards the **red** end
- This indicates that the galaxies are moving **away** from us
- If the galaxies are moving away from us it means that the **universe is expanding**

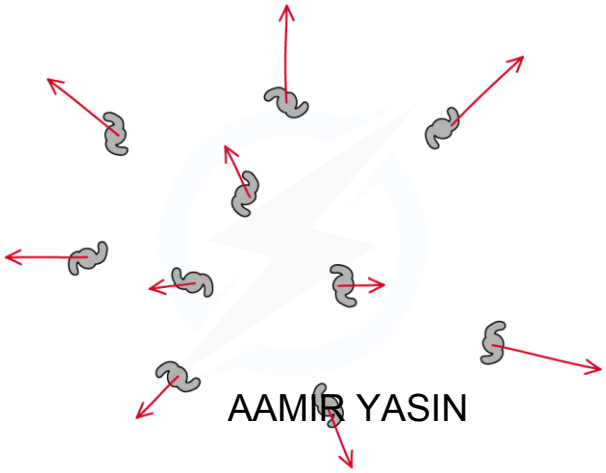
- The observation of redshift from distant galaxies supports the **Big Bang theory**
- Another observation from looking at the light spectrums produced from distant galaxies is that the **greater** the **distance** to the galaxy, the **greater** the **redshift**
    - This means that the **further away** a galaxy, the **faster** it is moving away from us



Graph showing the greater the distance to a galaxy, the greater the redshift

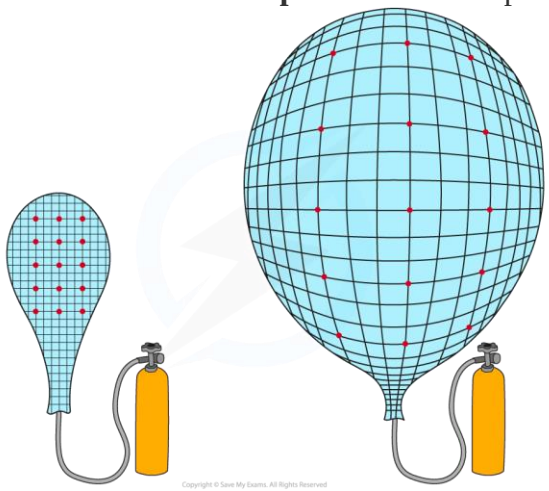
The Big Bang

- Around **14 billion years ago,** 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 the further away they are the faster they move
- **Redshift** in the light from distant galaxies is evidence that the Universe is expanding and supports the Big Bang Theory
    - As a result of the initial explosion, the Universe **continues to expand**



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

- An analogy of this is points drawn on a balloon where the balloon represents space and the 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 the same amount**
    - This is because the **space itself** has expanded between the galaxies



A balloon inflating is similar to the stretching of the space between galaxies

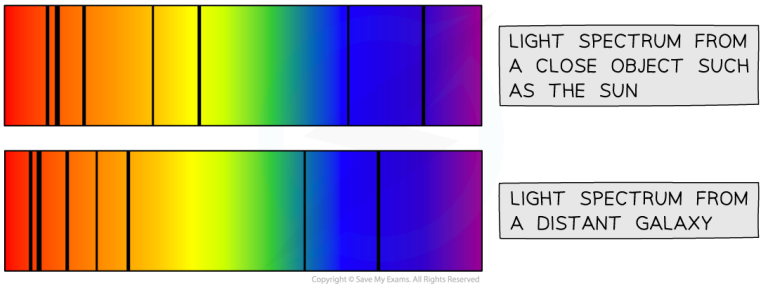
Redshift and CMBR

Evidence for the Big Bang

- The Big Bang theory is very well supported by evidence from a range of sources
- The main pieces of evidence are
  - **Galactic red-shift**
  - **Cosmic Microwave Background Radiation** (CMBR)

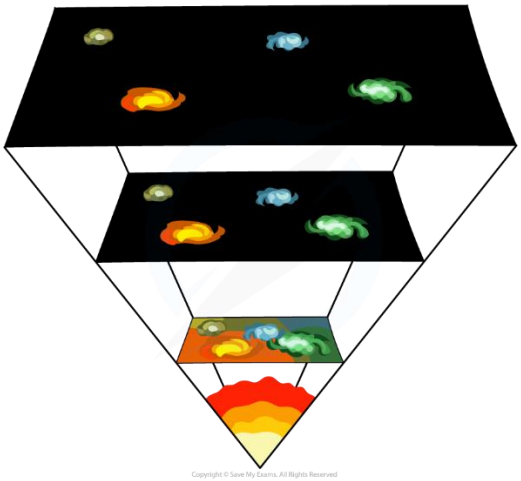
Evidence from Galactic Red-Shift

- Galactic redshift provides evidence for the Big Bang Theory and the expansion of the universe
- The diagram below shows the **light** coming to us from a **close object**, such as the Sun, and the light coming to the Earth from a **distant galaxy**



Comparing the light spectrum produced from the Sun and a distant galaxy

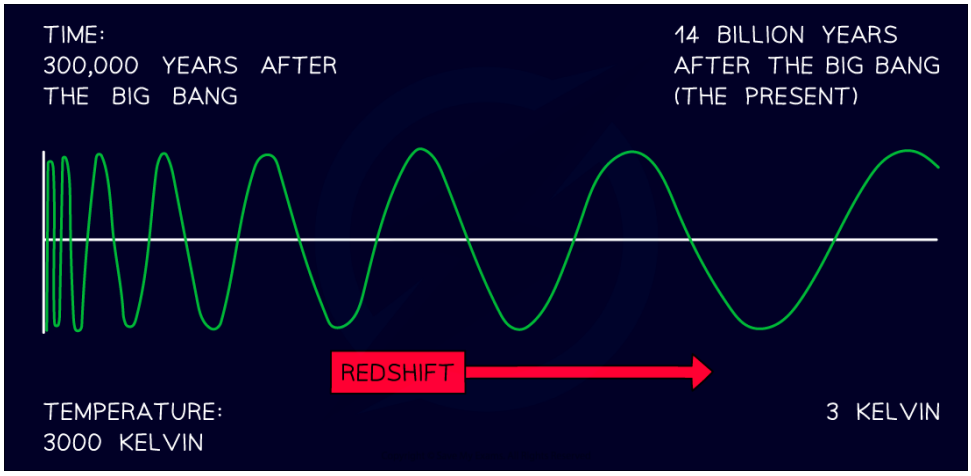
- Red-shift provides evidence that the Universe is expanding because:
- Red-shift is observed when the spectral lines from the distant galaxy move closer to the **red** end of the spectrum AAMIR YASIN
  - This is because light waves are **stretched** by the expansion of the universe so the wavelength increases (or frequency decreases)
  - This indicates that the galaxies are moving **away** from us
- Light spectrums produced from **distant** galaxies are red-shifted **more** than **nearby** galaxies
  - This shows that the **greater** the **distance** to the galaxy, the **greater** the **redshift**
  - This means that the **further away** a galaxy is, the **faster** it is moving away from the Earth
- These observations imply that the universe is **expanding** and therefore **support** the Big Bang Theory



Tracing the expansion of the universe back to the beginning of time leads to the idea the universe began with a "big bang"

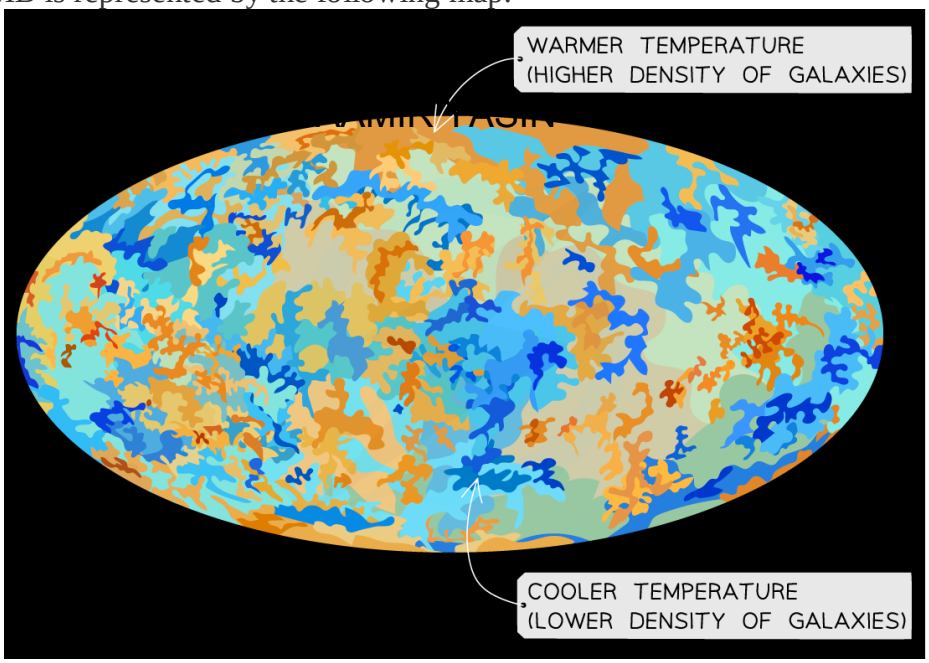
Evidence from CMB Radiation

- The discovery of the CMB (Cosmic Microwave Background) radiation led to the Big Bang theory becoming the currently accepted model
  - The CMB is a type of electromagnetic radiation which is a remnant from the early stages of the Universe
  - It has a wavelength of around 1 mm making it a microwave, hence the name Cosmic **Microwave** Background radiation
- In 1964, Astronomers discovered radiation in the microwave region of the electromagnetic spectrum coming from **all directions** and at a generally **uniform temperature** of 2.73 K
  - They were unable to do this any earlier since microwaves are **absorbed** by the atmosphere
  - Around this time, space flight was developed which enabled astronomers to send telescopes into orbit above the atmosphere
- According to the Big Bang theory, the early Universe was an extremely **hot** and **dense** environment
  - As a result of this, it must have emitted **thermal radiation**
- The radiation is in the **microwave** region
  - This is because over the past 14 billion years or so, the radiation initially from the Big Bang has become red shifted as the Universe has expanded
  - Initially, this would have been **high energy** radiation, towards the gamma end of the spectrum
  - As the Universe expanded, the wavelength of the radiation **increased**
  - Over time, it has increased so much that it is now in the **microwave** region of the spectrum



The CMB is a result of high energy radiation being redshifted over billions of years

- The CMB radiation is very **uniform** and has the exact profile expected to be emitted from a **hot body** that has cooled down over a very long time
    - This phenomenon is something that other theories (such as the Steady State Theory) **cannot** explain
- The CMB is represented by the following map:



The CMB map with areas of higher and lower temperature. Places with higher temperature have a higher concentration of galaxies, Suns and planets

- This is the closest image to a map of the observable Universe
- The different colours represent different temperatures
    - The **red** / orange / brown regions represent **warmer** temperature indicating a **higher density** of galaxies
    - The **blue** regions represents **cooler** temperature indicating a **lower density** of galaxies

- The temperature of the CMB radiation is mostly uniform, however, there are minuscule temperature fluctuations (on the order of 0.00001 K)
    - This implies that all objects in the Universe are more or less **uniformly spread out**

Measuring Galactic Speed & Distance

Using Redshift Observations to Measure the Universe

- The change in wavelength of the galaxy's starlight due to redshift can be used to find the velocity, *v*, with which a galaxy (or any distant object) is moving away from Earth
    - Using an equation to compare the ratio of the expected wavelength with the observed wavelength, the velocity can be found;

$$\frac{difference\ in\ actual\ wavelength\ and\ expected\ wavelegth}{actual\ wavelenght} = \frac{speed\ of\ galaxy}{speed\ of\ light}$$

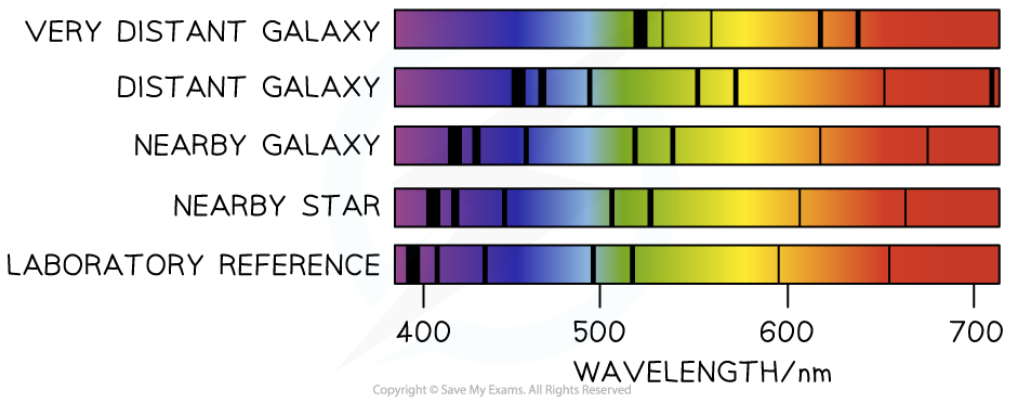
This equation will not be directly examined but the idea that the velocity of distant objects can be found from the redshift seen in easily observed wavelengths is an important one

Measuring Distance Using Supernovae

- Redshift and CMB radiation allow various measurements of the Universe to be accurately made
    - Measuring distance is done using different methods
    - A key method is the use of **standard candles**, including **supernovae**
- **Supernovae** are exploding stars
    - Certain types have the same peak level of brightness (**absolute magnitude**), making them extremely useful in measuring the distance to remote stars and galaxies
    - Type 1a supernovae are so bright that they can be seen clearly even though they may be deep inside their parent galaxy
    - This allows the distance to the galaxy to be calculated

Hubble Constant Calculations

- In 1929, the astronomer Edwin Hubble showed that the universe was **expanding**
    - He did this by observing the absorption line spectra produced from the light of distant galaxies
    - He discovered that the light was **shifted** towards the **red** end of the spectrum
- This **Doppler shift** in the wavelength of the light is **evidence** that distant galaxies are **moving away** from the Earth
- Hubble also observed that light from more distant galaxies was **more red-shifted** than the light from nearer galaxies
    - This observation showed that galaxies or stars which are **further away** from the Earth are **moving faster** than galaxies which are closer



Examples of redshifted line spectra for galaxies at different distances from the Earth compared to a laboratory sample

Hubble's Law

- Hubble's law states:

The recessional velocity *v* of a galaxy is proportional to its distance from Earth

- Hubble's law can be expressed as an equation:

$$v = H_o d$$

- Where:
  - H_0 = Hubble constant (s^{-1})
  - v = recessional velocity of an object, the velocity of an object moving **away** from an observer (km s^{-1})
  - d = distance between the object and the Earth (km)
- As the equation shows, the Hubble Constant, H_0 is defined as:

The ratio of the speed at which the galaxy is moving away from the Earth, to its distance from the Earth

- The accepted value of the Hubble constant is $H_0 = 2.2 \times 10^{-18}$ s^{-1}

Age of the Universe

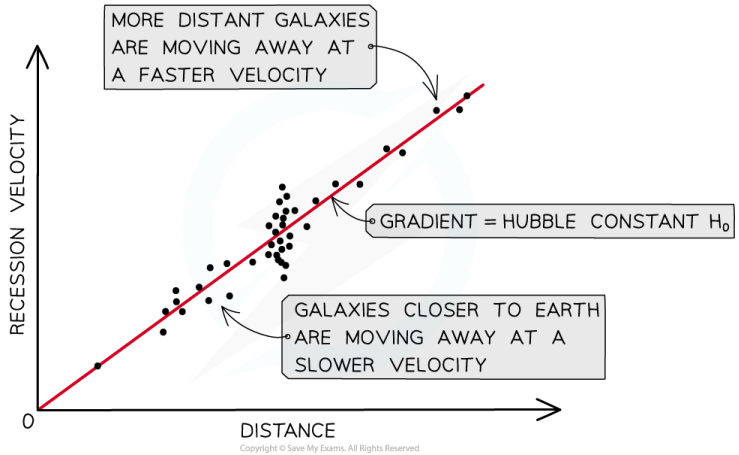
- Since Hubble's Law states that

$$H_o = d / v$$

- It can be rearranged to show that

$$1/ H_o = v / d$$

- Hubble's law shows that the further away a star is from the Earth, the faster it is moving away from us



A key aspect of Hubble's law is that the furthest galaxies appear to move away the fastest

- The gradient of the graph can be used to find the Age of the Universe
  - When the distance equals zero, this represents all the matter in the Universe being at a single point
  - This is the singularity that occurred at the moment of the Big Bang
- The units of the gradient are **per second** (the same as the units of the Hubble Constant)
  - By taking the reciprocal, or, the units will become seconds
  - Therefore the reciprocal of the gradient represents time and gives the amount of time which the Universe has been expanding for
- Astronomers have used this formula to estimate the age of the Universe at about 13.7 billion years