# Edexcel GCSE Physics

Your notes

## Cosmology

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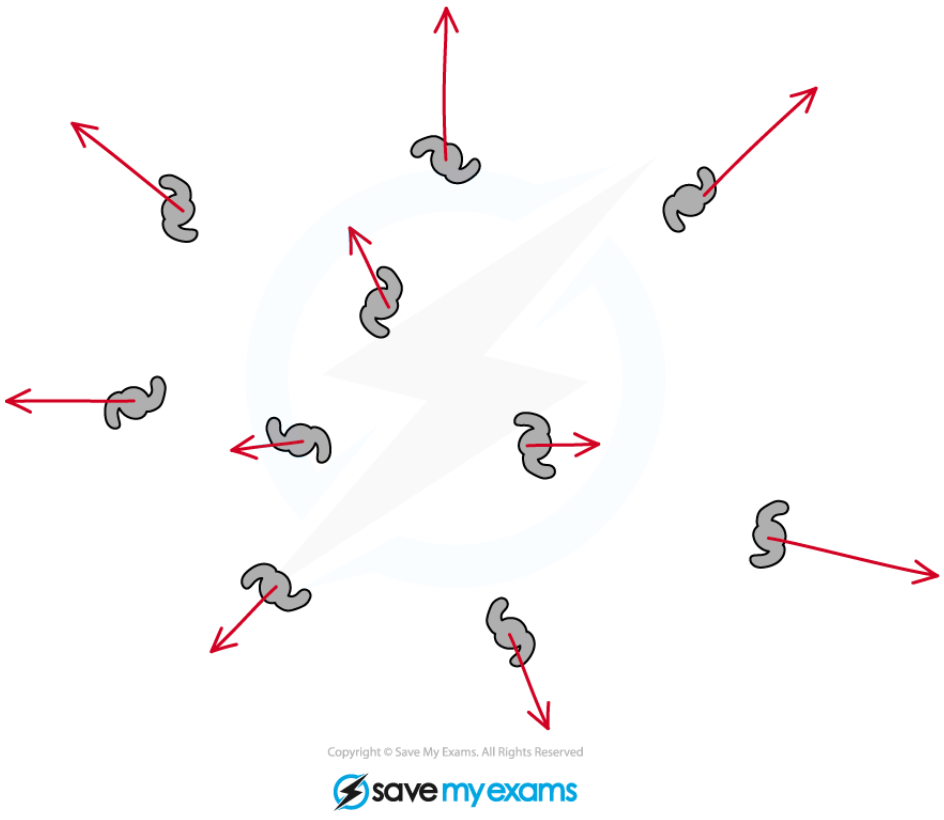
Your notes

# Big Bang & Steady State Theories

## The Big Bang Theory

- 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
- As a result of the initial explosion, the Universe **continues to expand**



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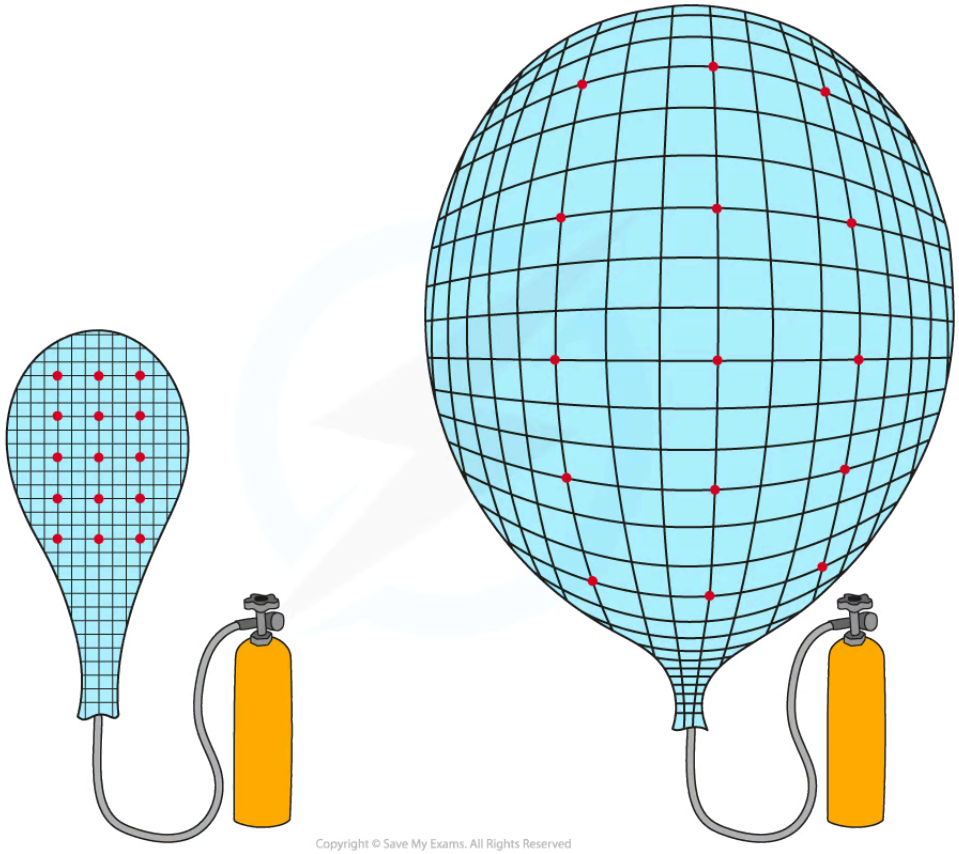
***All galaxies are moving away from each other, indicating that the universe is expanding***

- 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
  - Therefore, the **density** of galaxies **falls** as the Universe expands




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

## Steady State Theory

- The Steady State theory was the main rival to the Big Bang theory up until the mid-1960s
- The main idea behind the Steady State theory was that the Universe has **always existed** more or less as it is seen now

- The theory accounted for the expansion of the Universe by suggesting that as galaxies move apart, **new ones** will be formed in the gaps in between them
  - This implies the **density** of galaxies remains the **same** as the universe expands
- Whilst the Steady State theory could explain the expansion of the Universe it could not explain some of the other evidence that emerged in favour of the Big Bang and hence is not an accepted theory today

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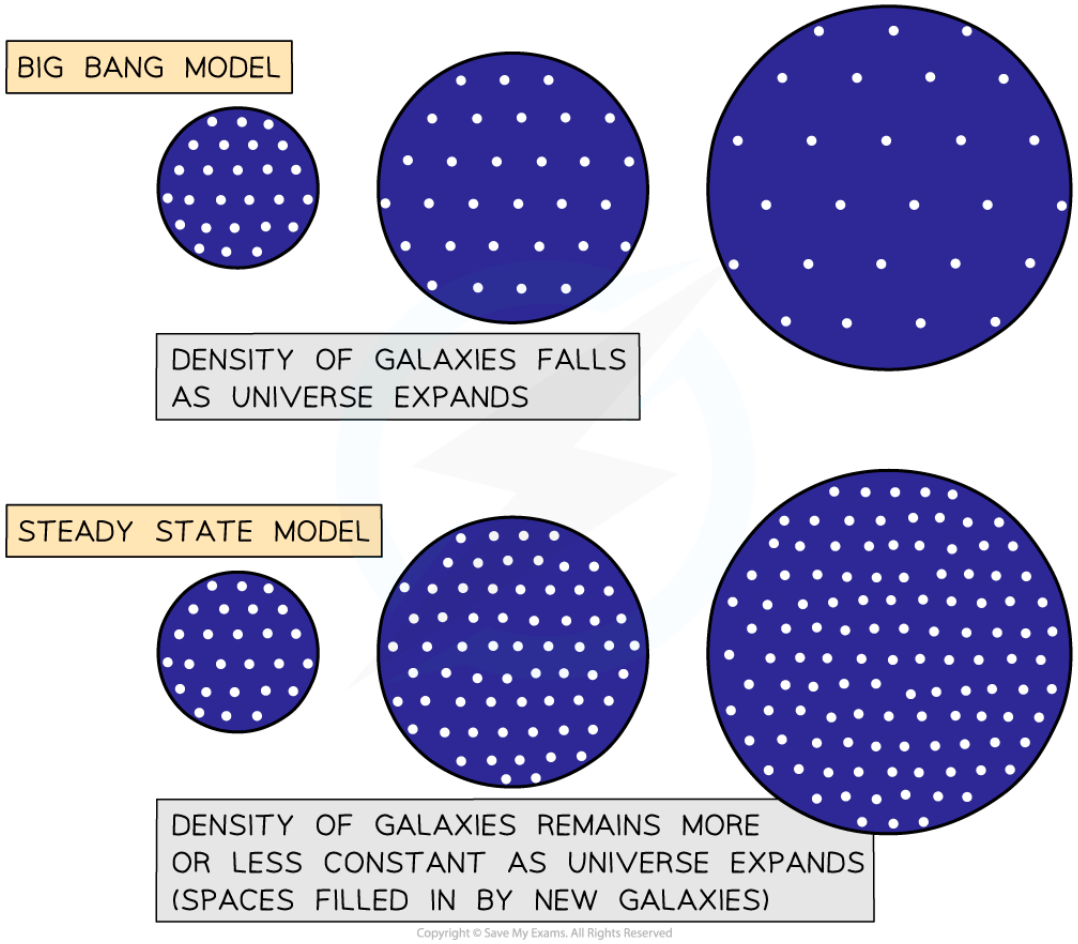


*The Steady State Theory vs the Big Bang Theory*

# Evidence for the Big Bang

- Since there is more evidence supporting the Big Bang theory than the Steady State theory, it is the currently **accepted model** for the origin of the Universe
- The main pieces of evidence for the Big Bang are
  - Galactic red-shift

- Cosmic Microwave Background (CMB) radiation

## Evidence from Galactic Red-Shift


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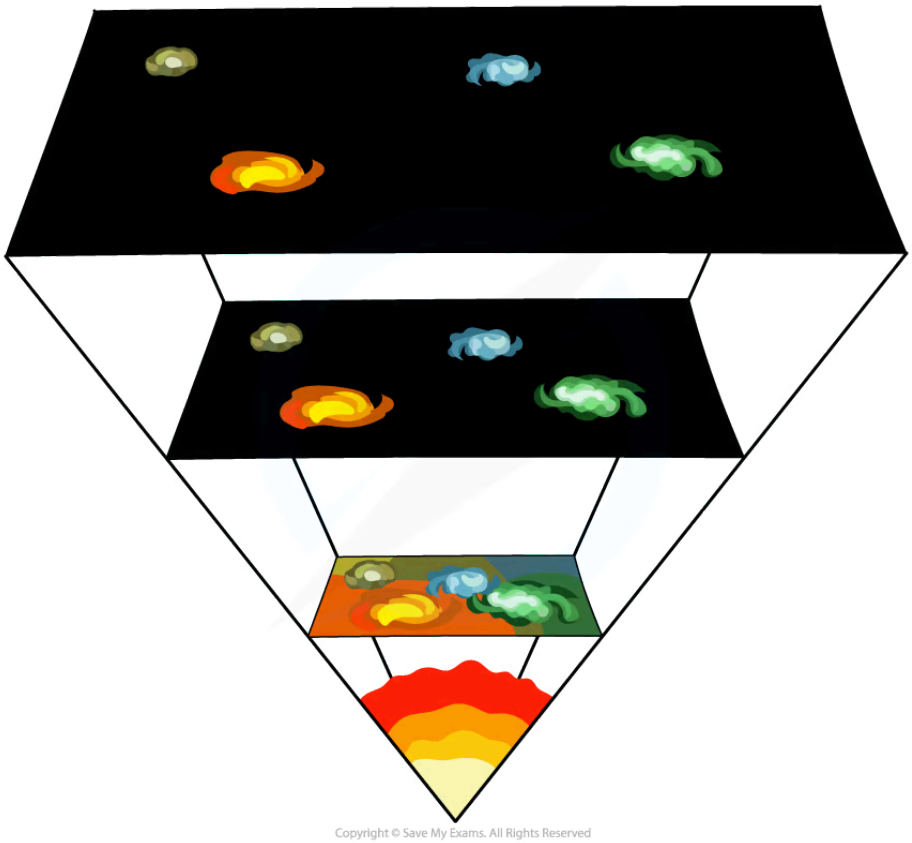
- By observing the **light spectrums** from supernovae in other galaxies there is evidence to suggest that distant galaxies are **receding** (moving further apart) even faster than nearby galaxies
  - These observations were first made in 1998
- The light spectrums show that light from distant galaxies is redshifted, which is evidence that the **universe is expanding**
- As a result, astronomers have concluded that:
  - All galaxies are moving away from the Earth
  - Galaxies are moving away from each other
- This is what is expected after an **explosion**
  - Matter is first **densely packed** and as it explodes it, it moves out in **all** directions getting further and further from the source of the explosion
  - Some matter will be **lighter** and travel at a **greater** speed, **further** from the source of the explosion
  - Some matter will be **heavier** and travel at a **slower** speed, **closer** to the source of the explosion
- If someone were to **travel back in time** and compare the separation distance of the galaxies:
  - It would be seen that galaxies would become **closer and closer together** until the entire universe was a **single point**
- If the **galaxies** were originally all grouped together at a single point and were then exploded a similar effect would be observed
  - The galaxies that are the **furthest** are moving the **fastest** - their distance is proportional to their speed
  - The galaxies that are **closer** are moving **slower**




*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

- According to the Big Bang theory, the early Universe was extremely **hot** and extremely **dense**
  - As a result of this, it must have emitted thermal radiation
- Astronomers discovered radiation in the **microwave** region of the electromagnetic spectrum which comes from all directions and has a temperature of 2.73 K
  - This is known as the Cosmic Microwave Background (CMB) radiation
- This radiation is thought to be the **remains** of the thermal energy from the Big Bang, spread across the whole Universe
- The radiation is in the microwave region because over the past 14 billion years or so, that radiation initially from the Big Bang has become **redshifted** as the Universe has **expanded**

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- 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


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## The Doppler Effect

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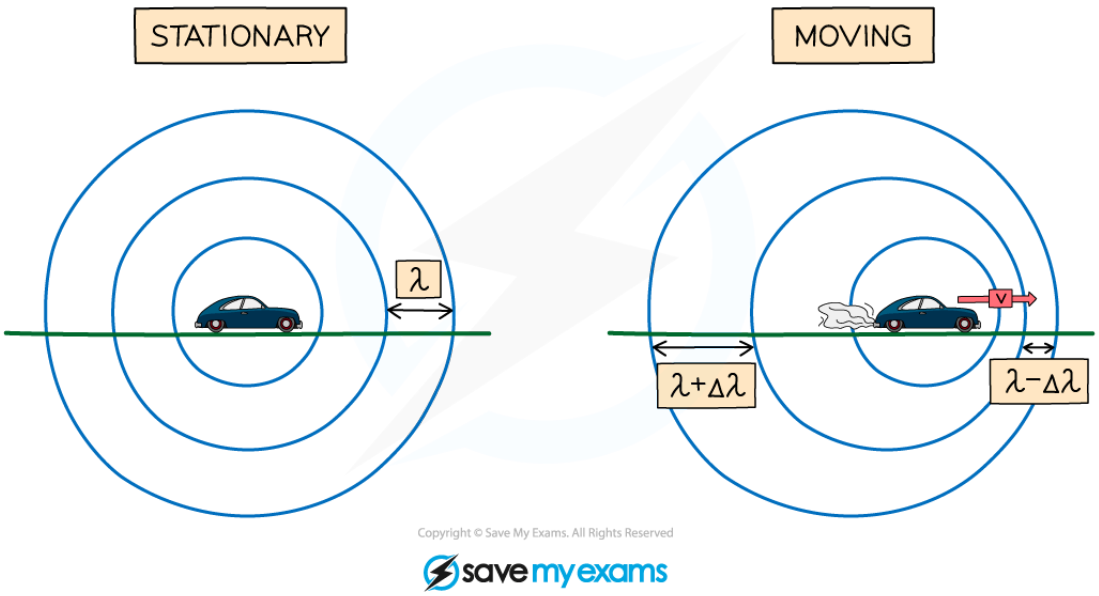
# The Doppler Effect

- 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
- Therefore, when a wave source moves relative to an observer there will be a change in the observed **frequency** and **wavelength**






***Wavefronts are even in a stationary object but are squashed in the direction of the moving wave source***

- 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** (λ – Δλ) and the **frequency increases**
  - The wavelength **behind** the source **increases** (λ + Δλ) and the **frequency decreases**
  - This effect is known as the **Doppler** effect
- Note: Δλ means '**change in wavelength**'

## Examiner Tips and Tricks

Although you will not be expected to do any calculations with the Doppler effect, it is important you remember the relationship between wavelength and frequency (wavelength increases, frequency decreases and vice versa)

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## Galactic Red-shift

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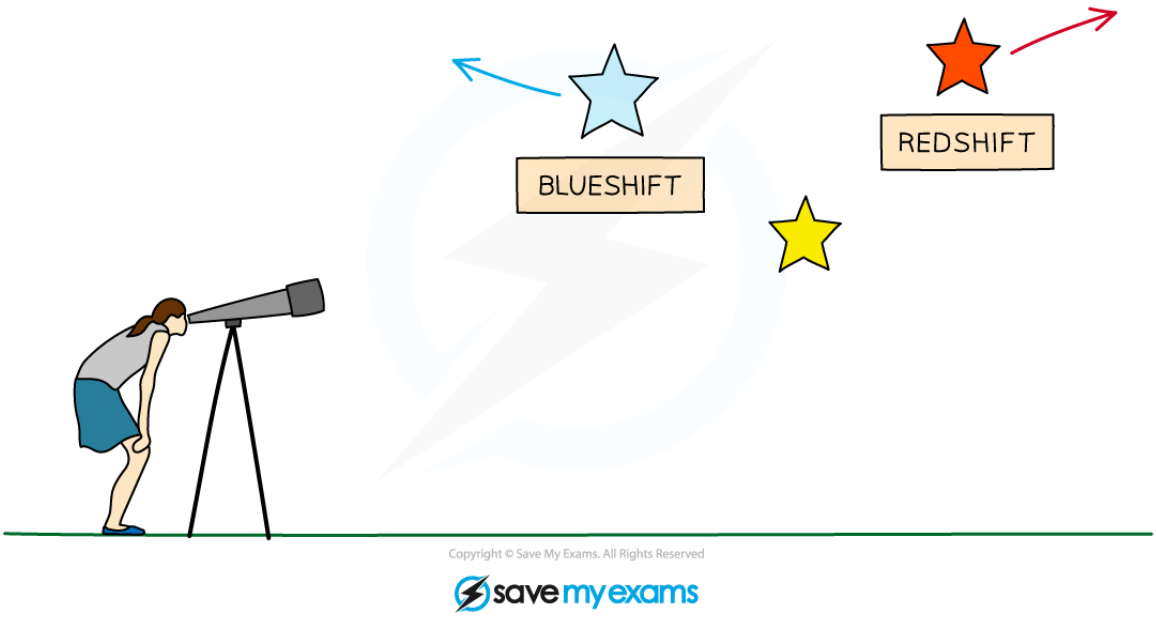
# Galactic Red-shift

- The Doppler effect affects all types of waves, including **light**
- Light emitted from stars and galaxies will be at a certain wavelength in the visible part of the electromagnetic spectrum
- 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
- If an object moves **towards** an observer the **wavelength** of light **decreases**
  - This is known as **blueshift** as the light moves towards the blue end of the spectrum






***Light from a star that is moving towards an observer will be blue shifted and light from a star moving away from an observer will be red shifted***

- An **increase** in wavelength is a **decrease** in frequency and vice versa

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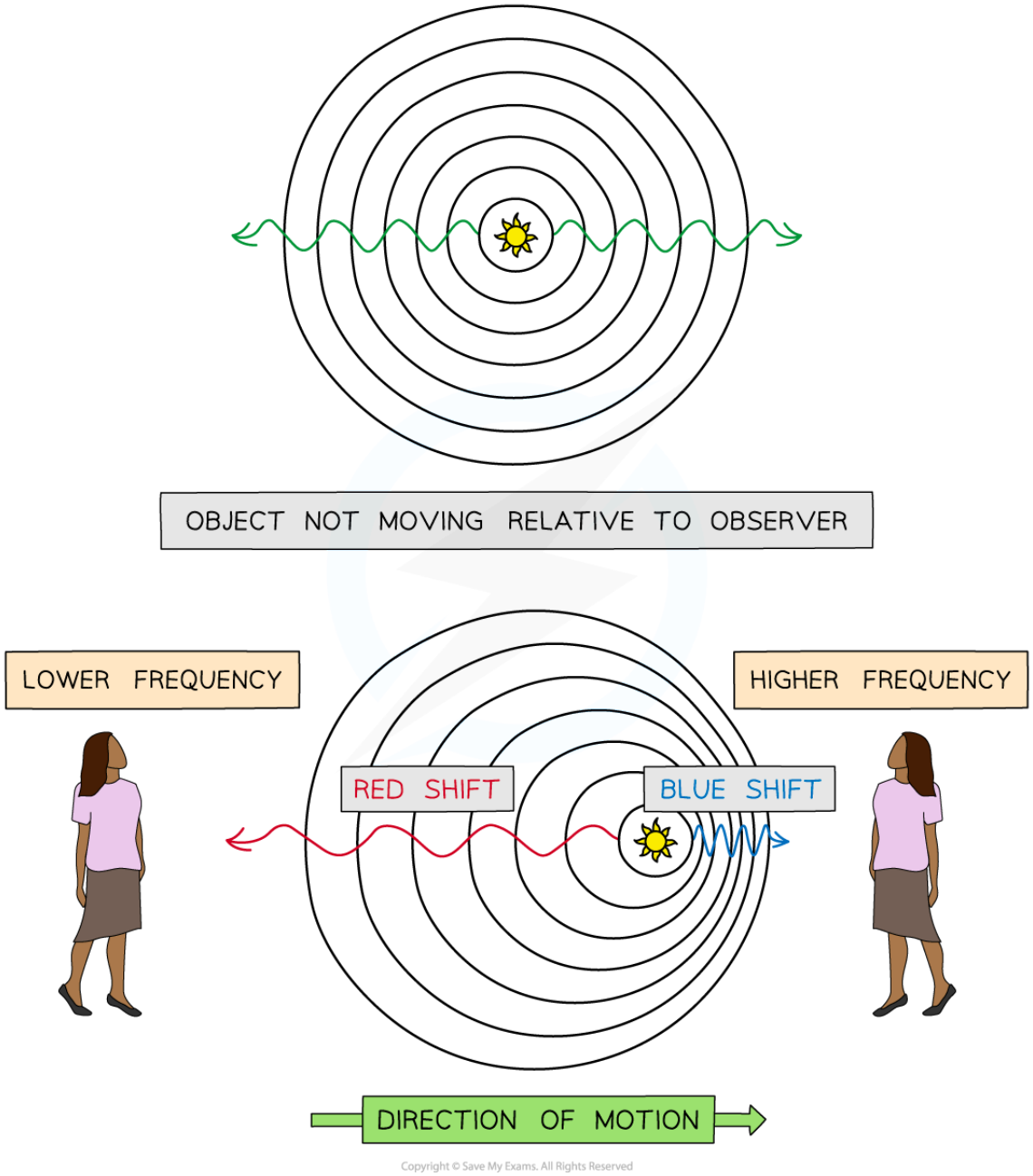
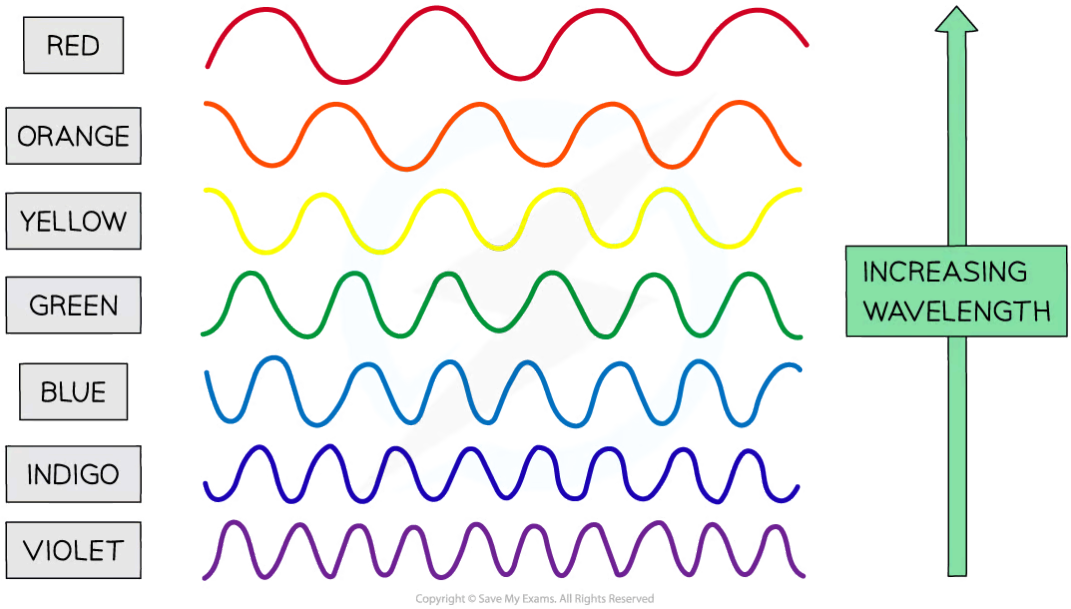



*The observer in front observes a blue shift, the observer behind observes a redshift*

### Examiner Tips and Tricks

You need to know that in the visible light spectrum **red light** has the **longest wavelength** and the **smallest frequency** compared to **blue light** which has a **shorter wavelength** and **higher frequency**




To help you to remember what happens to the wavelength and the frequency of an object as it moves further away, it is useful to think about how the sound of a **motorbike** would change as it travels **away** from you. As the motorbike travels away from you the pitch of the sound will become **lower**. This means the frequency of the sound is **decreasing**. If the frequency has decreased, the wavelength must also have increased.

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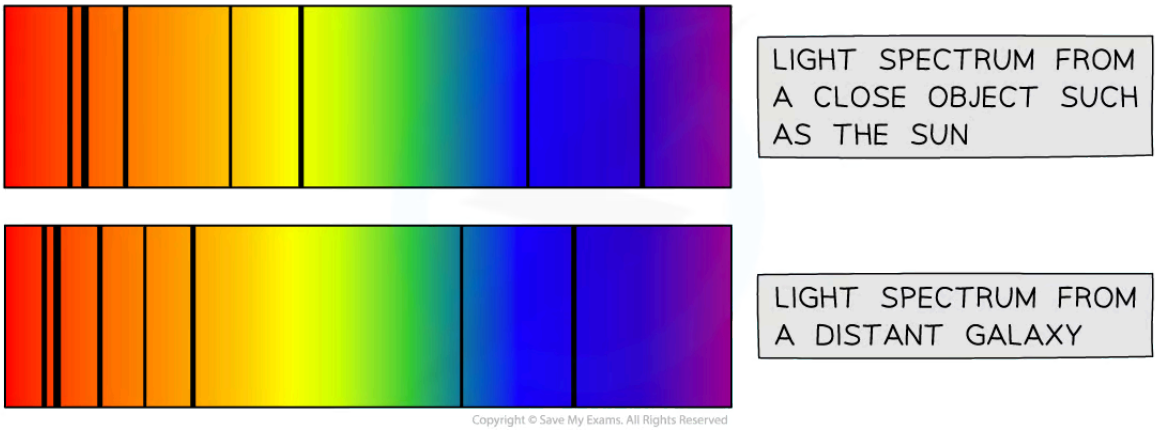
# The Expanding Universe

- Galactic redshift provides evidence for the Big Bang Theory and the expansion of the universe
- The diagram below shows the **light** coming to the Earth 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
  - 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

# Red-shift & the Origin of the Universe

- Both the **Big Bang** and **Steady State** theories of the origin of the Universe account for the red-shift of galaxies
- The fact that light from distant galaxies is **redshifted** shows that the galaxies are:
  - Moving away from the Earth
  - Moving away from each other
- This is a predicted consequence of the universe expanding from some **initial point** (as implied in the Big Bang Theory):

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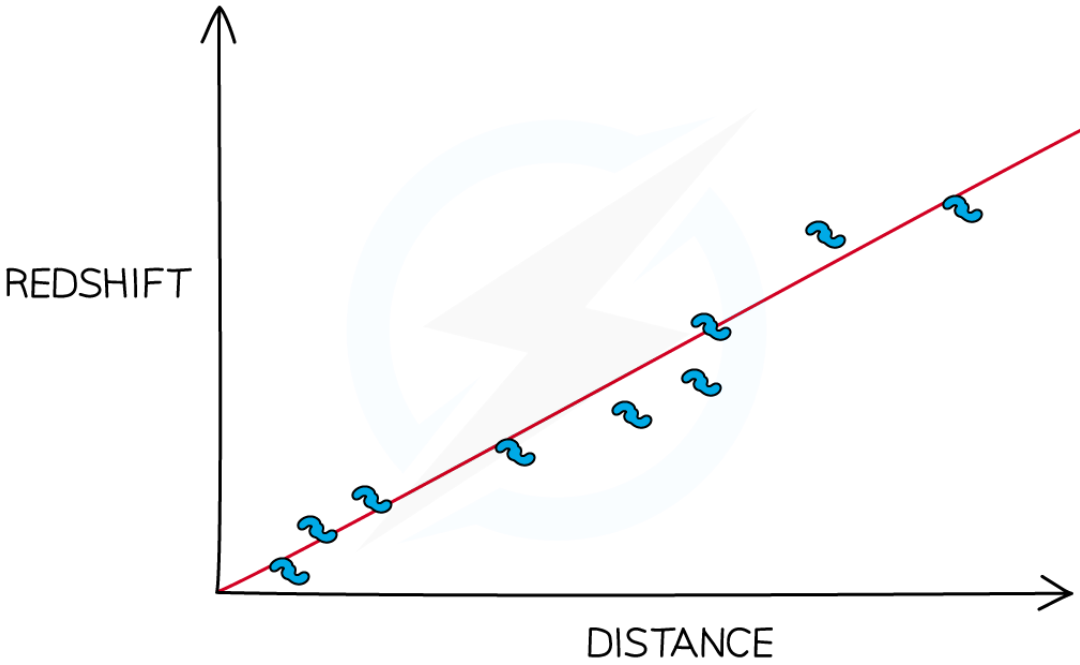
- Suppose the galaxies were originally all grouped together and then started to spread out at different speeds
- The galaxies that are moving fastest would move the furthest – the distance they move would be proportional to their speed - exactly the sort of relationship shown in the following graph






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

- The Steady State Theory, however, **does** also account for the redshift of galaxies
- It suggested that as galaxies moved apart, new ones were created in the space in between, resulting in a universe that remains the same over time
  - This means that more distant galaxies are still seen to have a greater redshift
- However, the Steady State Theory does **not** support the evidence from the Cosmic Microwave Background radiation, and hence is no longer a supported theory

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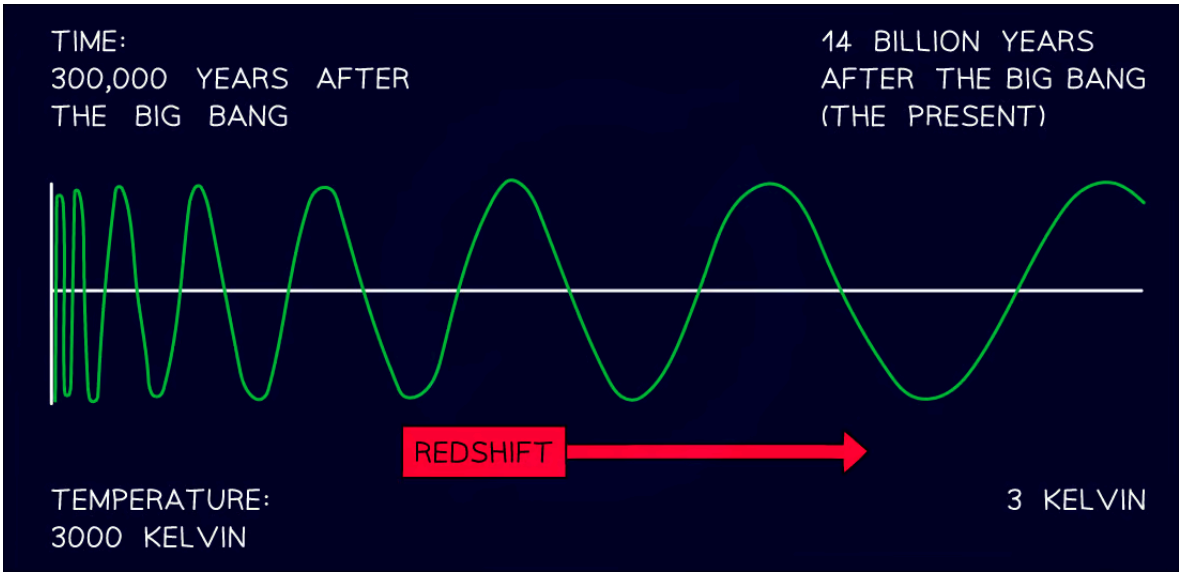
# The Cosmic Microwave Background

- The discovery of the CMB (Cosmic Microwave Background) led to the Big Bang theory becoming the currently accepted model since it is not supported by the Steady State theory
  - 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
- 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 redshifted 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

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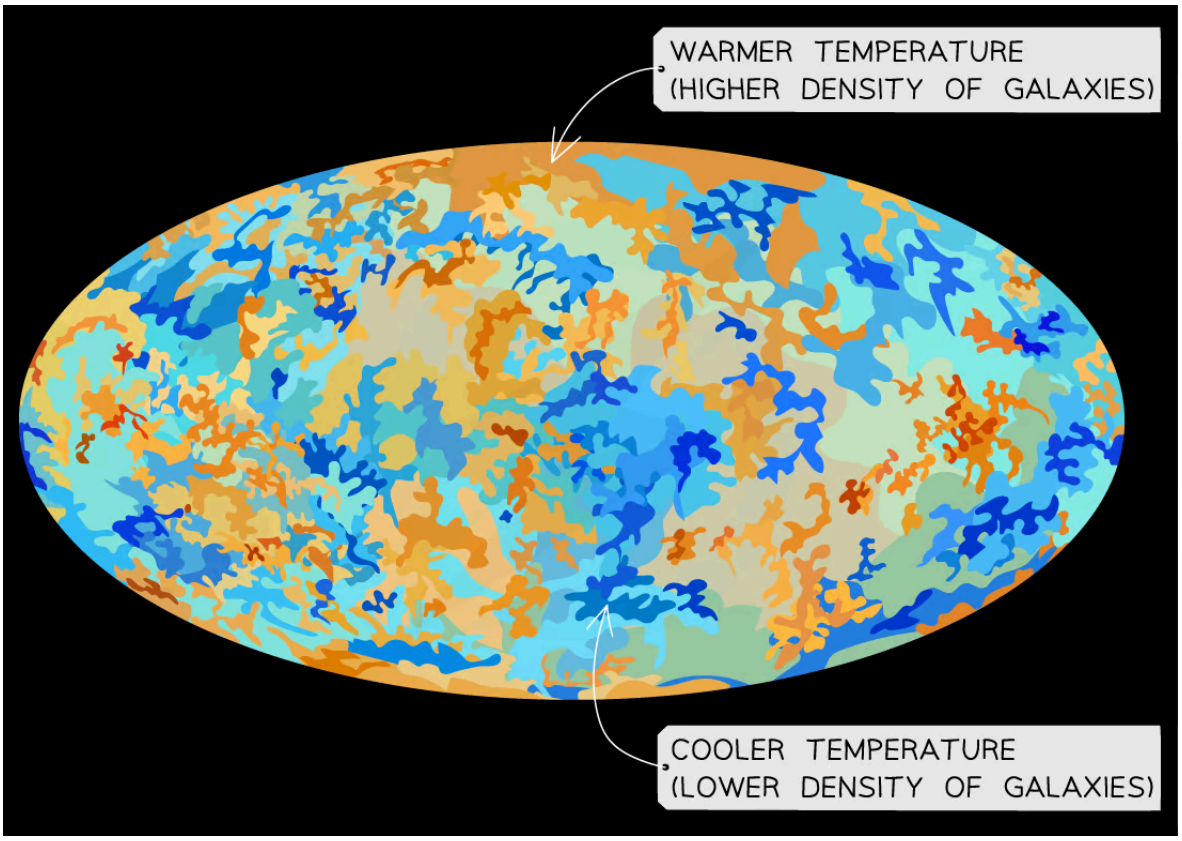
***The CMB is a result of high energy radiation being redshifted over billions of years***

- 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 Universe
- The different colours represent different temperatures
  - The **red** / orange / brown regions represent **warmer** temperature indicating a **higher density** of galaxies
  - The **blue** / green regions represents **cooler** temperature indicating a **lower density** of galaxies
- The temperature of the CMB 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**

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## Observing the Universe

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# A Short History of Astronomy

- Methods of observing the Universe have changed drastically over time
- Throughout history, astronomy has played an important role in human society
  - Not just because of mankind's fascination with the heavens but also in **navigation** and **agriculture**
- Ancient astronomers split the night sky into **constellations** to help them remember the stars
  - They knew that some constellations only ever appeared in the northern skies, whilst others lay to the south
- They also aligned monuments with the position of certain stars or the position of the Sun on certain days of the year, and these helped them to keep track of the **seasons**
- One example is the Callanish Stones in the Isle of Lewis and Harris, Scotland
  - These are an arrangement of standing stones placed in a cruciform pattern with a central stone circle 13 metres (43 feet) in diameter
  - They were constructed specifically in line with the movements of the Sun and Moon, 5000 years ago

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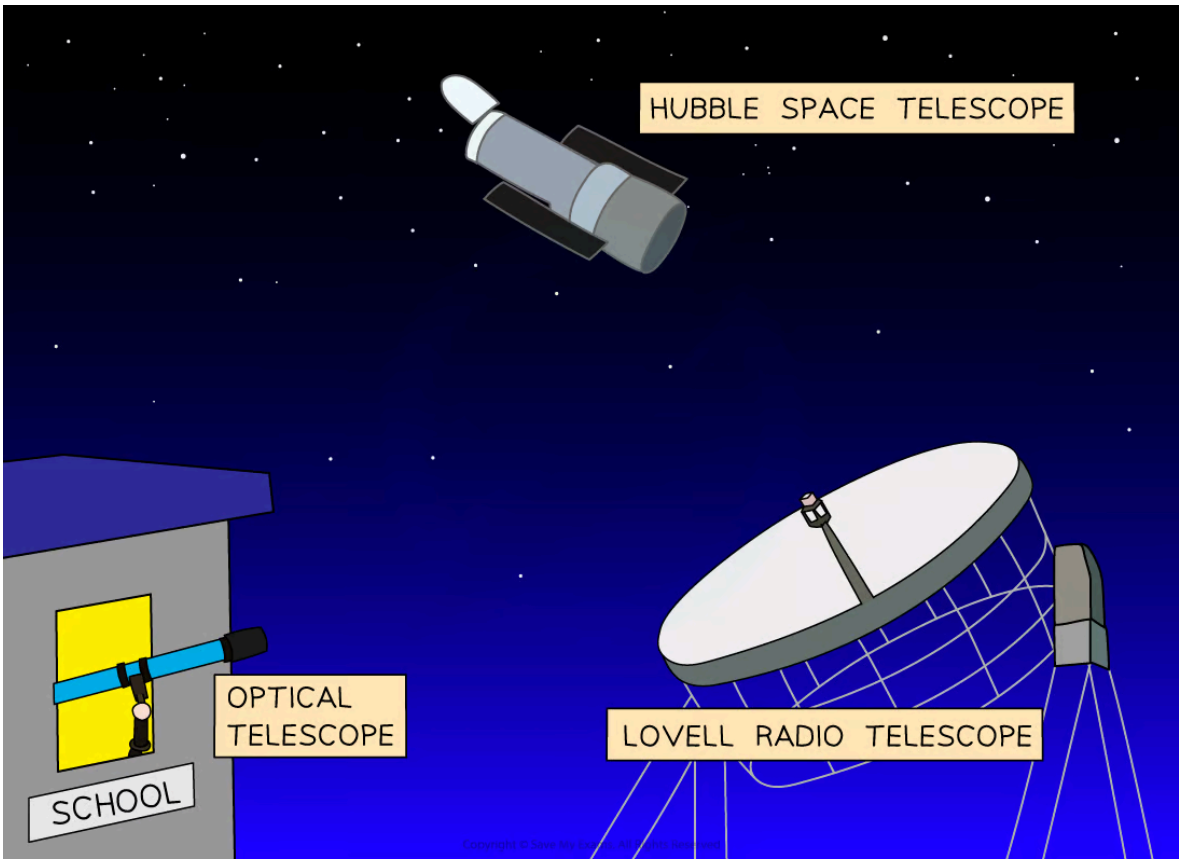
*The Callanish stones were used to track the movements of the Sun and the Moon*

## Modern Telescopes

- The most important development in astronomy was the invention of the astronomical telescope in the early 17th century
- Early telescopes allowed astronomers to:
  - Observe the features of planets and moons for the first time
  - Develop more accurate models of the solar system, for example, the **heliocentric model** of the Solar System
- Modern telescopes provide much more data than the telescopes used hundreds of years ago, this is because:
  - They can detect **more wavelengths/frequencies** in the EM spectrum than just visible light
  - They can be positioned **above the Earth's atmosphere** where less radiation is absorbed

- They can detect **weaker signals**
- They have a much **greater magnification**
- They are much more **powerful**
- Technology has improved so computers can **process** and **improve the data**

- Modern telescopes come in several shapes and sizes
  - These can range from smaller telescopes found in a classroom to giant radio telescopes, such as the Lovell Telescope based at the Jodrell Bank Observatory in Cheshire




***Modern telescopes are a range of different sizes and can be on Earth on in space, depending on their use***

## Telescopes in Space

- The atmosphere can substantially restrict the quality of astronomical observations, such as:
  - Reflection of light from moisture in the atmosphere causing light pollution

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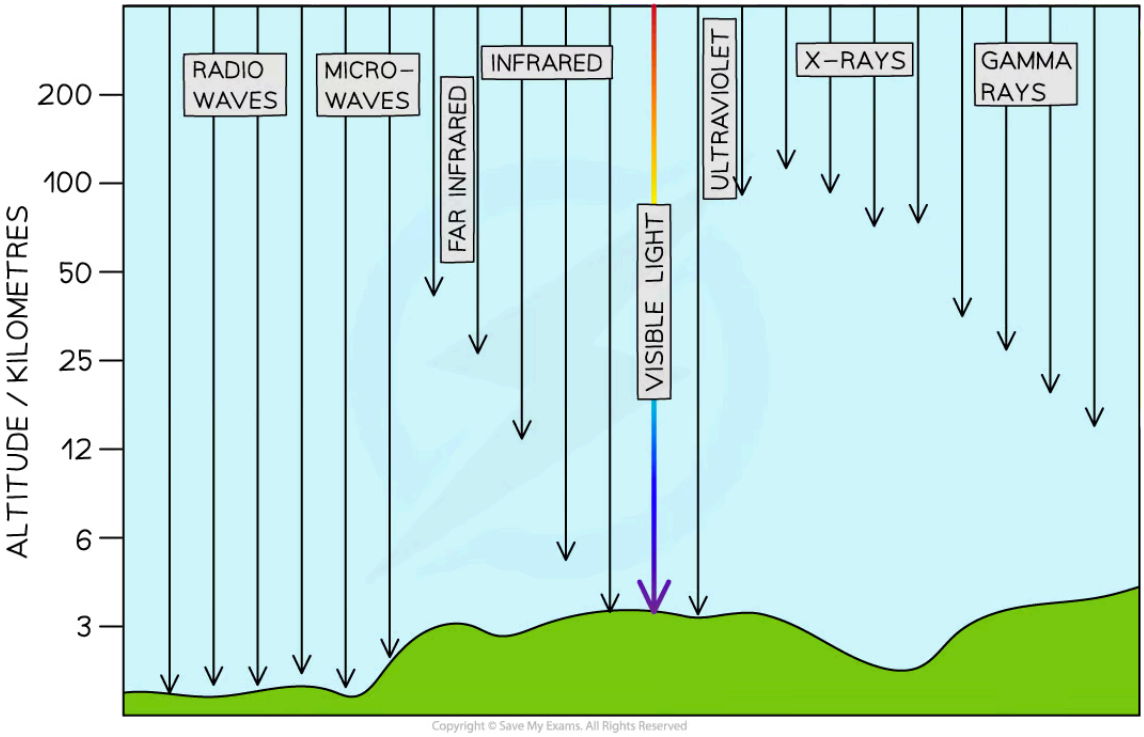
- Air currents distorting the path of starlight

- As well as this, not all electromagnetic radiation coming from space reaches the Earth's surface
- The atmosphere **absorbs** certain wavelengths of electromagnetic waves restricting observations from astronomical objects that produce these, such as:
  - Near (short-wavelength) microwaves
  - Far (long-wavelength) infrared
  - Near (short-wavelength) ultraviolet
  - X-rays
  - Gamma rays




***Some wavelengths of the electromagnetic spectrum are absorbed by the Earth's atmosphere***

- To get around these problems, telescopes are often launched into space
  - The most famous of these is the Hubble Space Telescope (this detects UV, optical, and near-infrared)
  - Others include the Chandra X-ray telescope and the Spitzer infrared telescope

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- The **benefits** of space telescopes are:
  - They lead to the **discovery** of objects not detectable by visible light
  - More **information** and **data** can be collected
  - Different EM waves can give different types of information about astronomical objects
  - They can produce much more **detailed** and **magnified** images
  - They produce **clearer** images which are unaffected by Earth's atmosphere and light pollution
- The **downsides** of space telescopes are:
  - The telescopes are much **harder to repair**
  - They cannot be made too large since they need to fit into a rocket to be launched
  - They are much more **expensive**


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