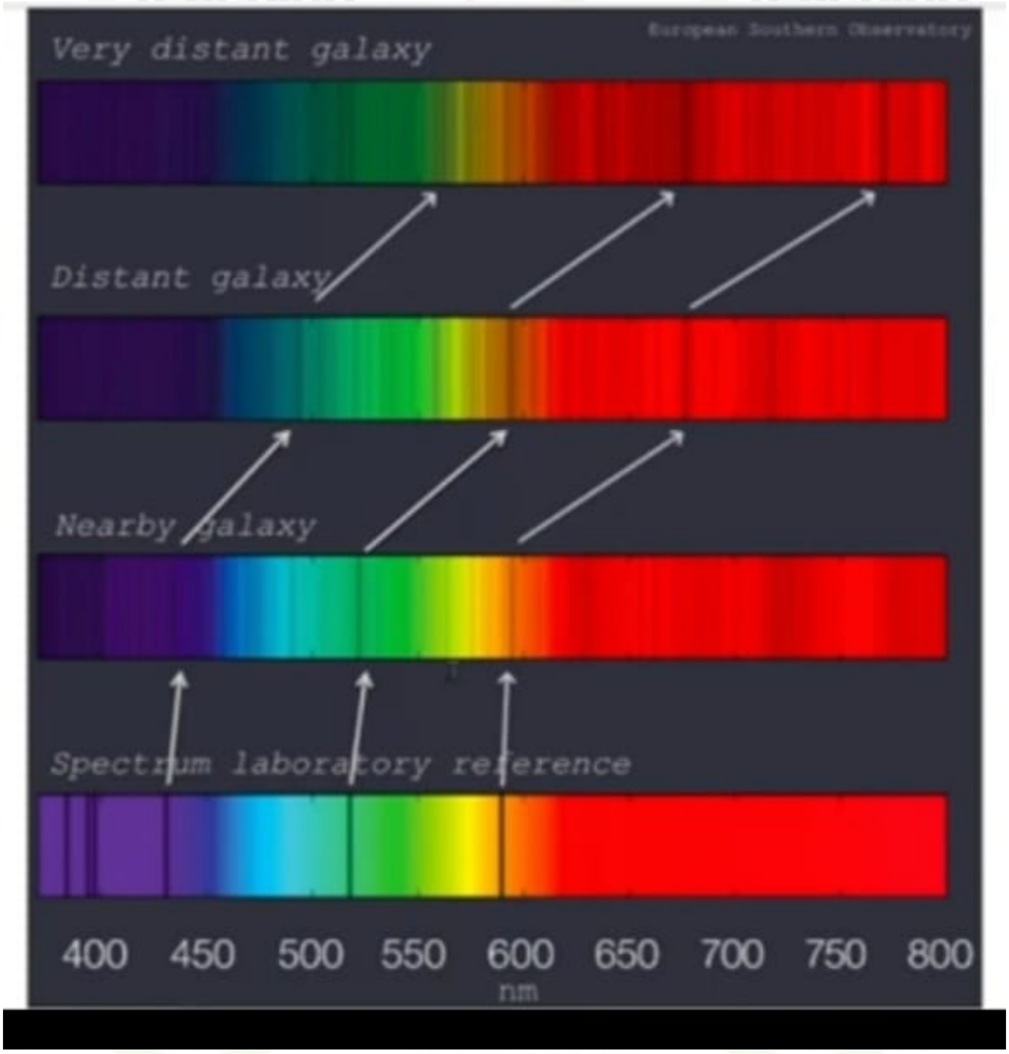
The Hubble constant

- When Edwin Hubble looked at the absorption spectra of distant galaxies, he determined a relationship b/w a speed of a galaxy and its distance from Earth.

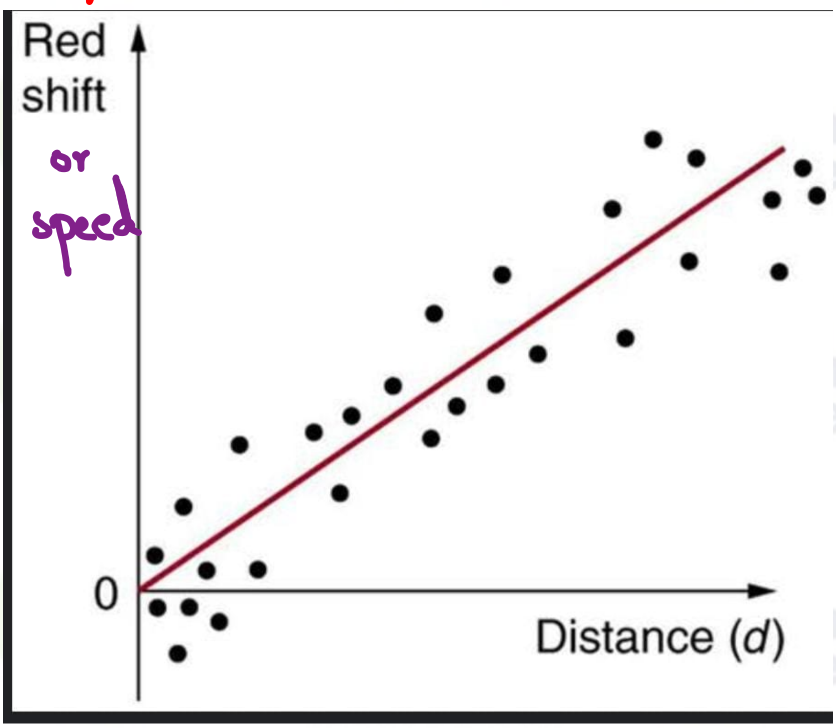
Comparing red shifts of galaxies



Hence, Hubble discovered that all galaxies show redshift, indicating they are moving away and galaxies that are further away show a greater increase in red shift.

- Hubble Diagram:- A plot of recession velocity (speed with which galaxies are moving away) against distance for galaxies is close to a straight line.

Relationship between redshift and galaxy distance



$v \propto d$

Hubble's law tells us the greater the distance to a galaxy, the greater the redshift or speed with which it moves away from Earth.

This is Hubble law which states:

The speed of recession is proportional to distance of galaxy away from Earth.

- Recession speed means the speed at which something is moving away.
- This means a further away a galaxy is from Earth:
  - the faster it is moving away
  - the greater the increase in red shift.
- Hubble's law can be expressed as equation

$$v = H_0 \times d$$

- H_0 = Hubble constant (per second).
- v = recessional velocity of an object, the velocity of an object moving away from observer. (km/s)
- d = distance between the object and the Earth (km)

Measuring recession speeds of galaxies

- The recession speed v (how fast it is moving away from Earth) can be found from the change in wavelength of the galaxy's star light due to redshift.

  change in wavelength ∝ speed (recessional)

Measuring distance using supernova

- The distance (d) to a galaxy can be determined using the brightness of a supernova in that galaxy.

- Supernova are exploding stars
- Certain types of supernova have the same peak level of brightness (absolute magnitude) meaning they can be used as standard candles.

- These supernova are so bright that they can be used for measuring distances to most distant galaxies.

Hence; $V = H_0 \times d$ → distance of galaxy [Standard candle]

- V → recessive velocity [Doppler red shift]
- H_0 → Hubbles constant of proportionality

Age of the Universe

- Hubbles law can be rearranged to give the expression:

$$\frac{1}{H_0} = \frac{d}{v}$$

- Since the time is equal to distance divide by speed, the term $\frac{1}{H_0}$ represents an estimate of the age of the universe

- Hubble's law provide further evidence for the Big Bang:-

- It shows that the universe has been expanding since the beginning of time.
- If we looked at time in reverse, we would see galaxies were closer together in past.
- This suggests that the universe must have originated from a single point and has been expanding outward ever since.

Cosmic microwave background radiation

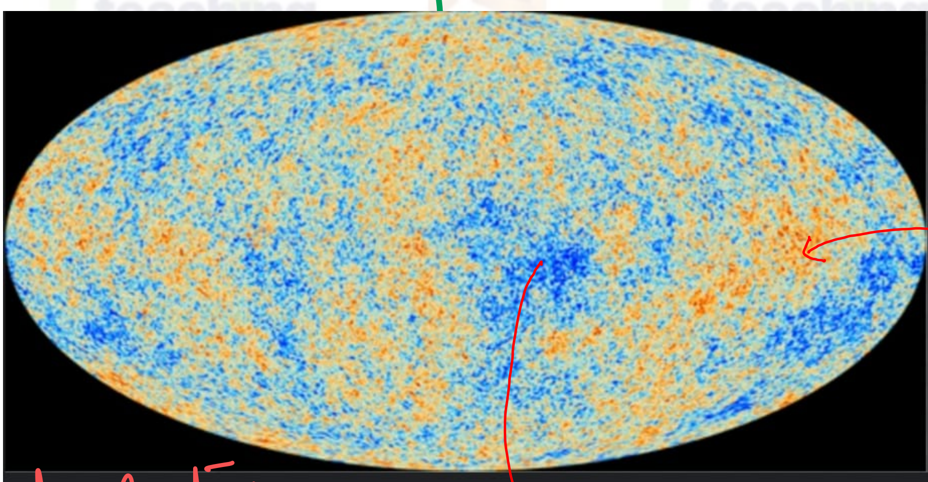
https://www.youtube.com/watch?v=v5dNE43Z4J4

- Cosmic microwave background radiation (CMBR) is a form of electromagnetic radiation that was emitted shortly after the beginning of the Universe (roughly 300,000 years after Big Bang)
  - At that time, the universe was incredibly hot, dense and nearly uniform in temperature and density.
- It is detected everywhere throughout the universe.

Note:-

- The CMBR map is the closest image that exists to a map of universe.
- It shows that the temperature of the Universe, and therefore the objects in it are more or less uniformly spread out.

CMBR map of the Universe



This color coding does not represent actual temperatures.

Color coding of CMBR

- red - high density, high temperature
- blue - low density, low temperature

Warmer temperature, Higher density of galaxies.

Cooler temperature, Lower density of galaxies.

The CMBR map shows areas of higher and lower temperature in the Universe. Regions with higher temperatures have a higher concentration of galaxies, Suns and planets.

Evidence from CMBR:-

- CMBR provides evidence for the Big Bang because

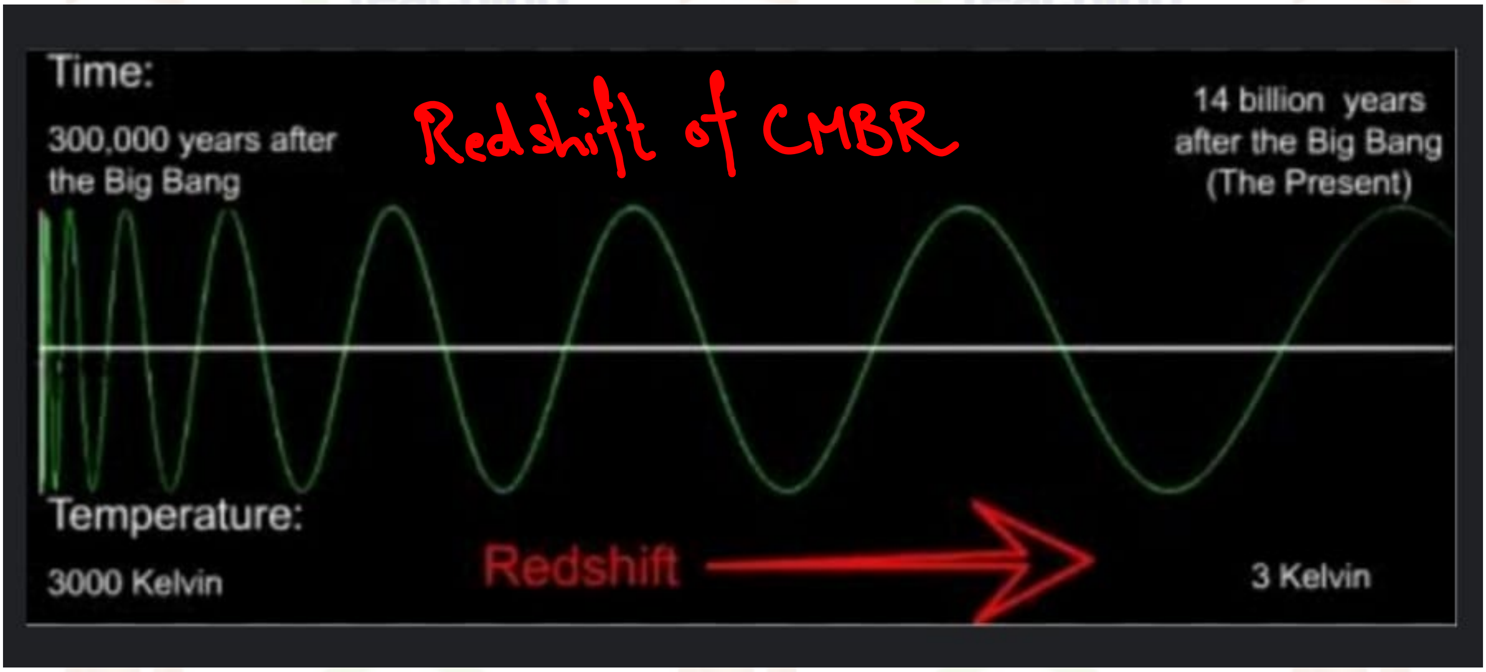
1. Theory predicts the early universe was extremely hot and dense.
   - Therefore, CMBR would have initially existed as short-wavelength gamma radiation.
   - The shorter wavelength in the past indicates the Universe must have been very hot in the beginning.
2. CMBR is consisent with radiation that has been stretched over time.
   - The Big Bang would have released a lot of energy in the form of extremely high-energy gamma radiation.
   - As the universe expanded, the wavelength of radiation increased.

- Over time it has been red-shifted so much that it is now in the microwave region of the spectrum.

3. CMBR can be interpreted as the radiation left over from the Big Bang.

- The CMBR is extremely uniform which indicates the Universe was much smaller than it is now.

Note:
- At that time, the universe was incredibly hot, dense and nearly uniform in temperature and density.



CMBR is a result of high-energy radiation being redshifted over a billions of years.

Q1) Describe and explain what can be deduced about the history of the Universe from the CMBR.

Ans:- Microwave radiation is detected from all directions at a similar intensity. This is the radiation produced just after the formation of the Universe. When the universe was formed, the radiation was high in energy and short in wavelength. Now it has less energy and a longer wavelength. This is because the Universe has expanded and cooled causing the wavelength to increase. This suggests the universe was initially very small and very energetic and has been expanding since.

$V = H_0 d$

- From the above equation, the Hubble constant, H_0 can be defined as:

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

- The accepted value of Hubble's constant is

$H_0 = 2.2 \times 10^{-18}$ per second

Measuring recession speed and distance

- The Hubble constant H_0 can be determined from measurnments of:
  - ★ red shift of light emitted by a galaxy
  - ★ the brightness of supernova in the galaxy

A star is receding from the Earth with a speed of $5.3 \times 10^4\,\text{km}\,\text{s}^{-1}$.

The Hubble constant, H_0, has a value of approximately $2.4 \times 10^{-18}\,\text{s}^{-1}$.

What is the approximate distance of the star from the Earth?

A $2.2 \times 10^{22}\,\text{m}$ **B** $1.3 \times 10^{23}\,\text{m}$ **C** $2.2 \times 10^{25}\,\text{m}$ **D** $1.3 \times 10^{26}\,\text{m}$