

A2 PHYSICS 9702

Crash Course

PROSPERITY ACADEMY

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**ASTRONOMY AND
COSMOLOGY**

COMPLETE NOTES



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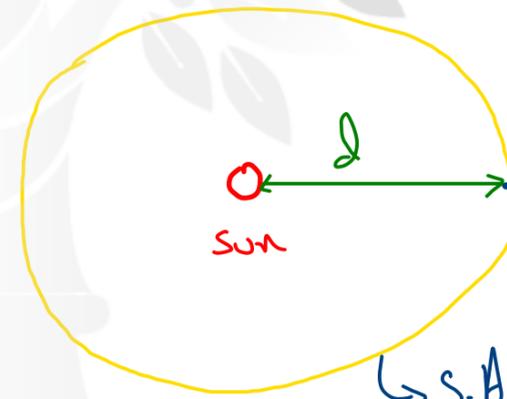
Astronomy & Cosmology

Luminosity (L) :- Total power delivered by a star

Radiant flux density (F) :- ① Observed amount of intensity of earth

② Observed amount of power transmitted normally through a surface, per unit area as measured on Earth

$$F = I = \frac{P}{A} = \frac{L}{4\pi d^2} = F$$



↳ S.A of a sphere = $4\pi r^2$

Some important units:-

① 1.0 Au (Astronomical unit) = 1.5×10^{11} m
1.0 Au is the average distance between the earth and the sun

$$\begin{aligned} 1 \text{ Au} &: 1.5 \times 10^{11} \text{ m} \\ n \text{ Au} &: 2.5 \times 10^{28} \text{ m} \end{aligned}$$

② Light year:- Unit of distance. It is the distance light travels in an earth year.

$$d = v \times t \Rightarrow (3 \times 10^8) \text{ m s}^{-1} \times (1 \times 365 \times 24 \times 60 \times 60) \text{ s}$$

$$d = 9.4608 \times 10^{15} \text{ m} = \text{Light year}$$

$$1 \text{ Ly} = 9.4608 \times 10^{15}$$

$$n \text{ Ly} : 3 \times 10^{30} \text{ m}$$

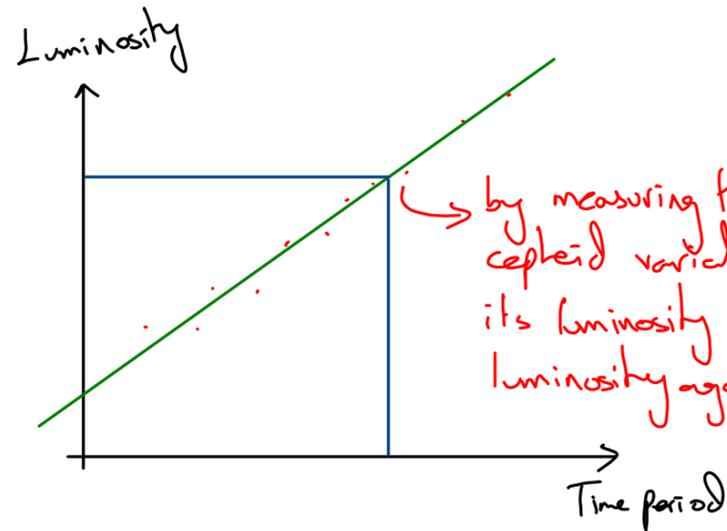
Our mission to find the age of the universe:-

Cosmic distance ladder:- It is the succession of steps/methods by which we determine the distance to celestial objects.



Standard Candle / Standard:- It is an astronomical object which has a known luminosity due to a characteristic quality possessed by that class of object.

→ Cepheid Variable:- It is defined as a type of star having a periodic pulsating brightness varying in both temperature and diameter with a well defined amplitude.



→ by measuring the time period of any cepheid variable, we can work out its luminosity as the graph of luminosity against time period is a straight line

→ Type 1A Supernova:- (constant luminosity each time)

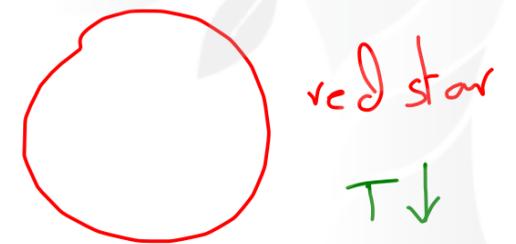
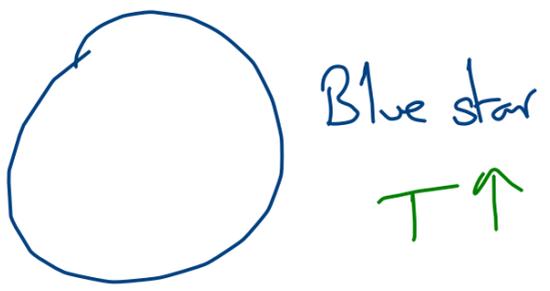
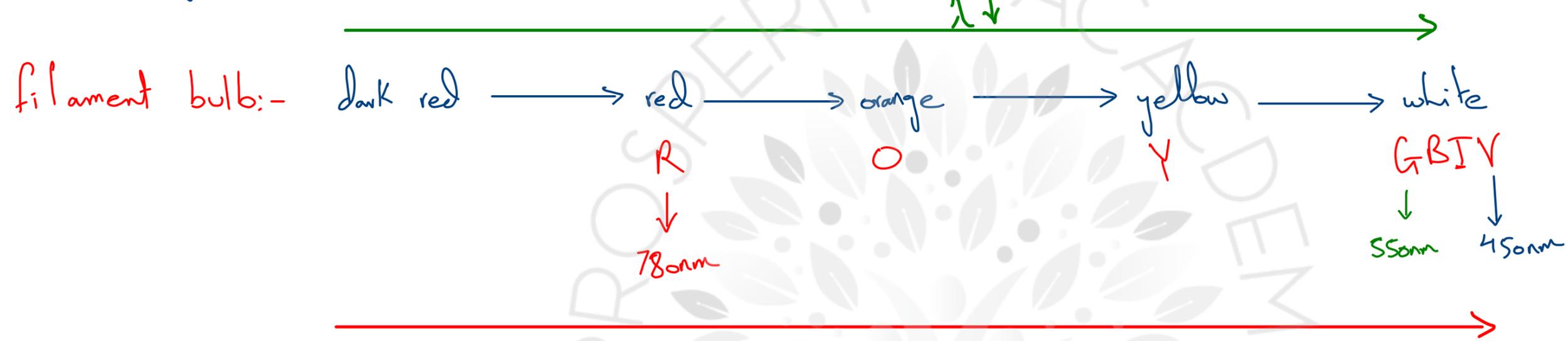
- As massive stars fuse hydrogen and other light elements into iron, they use up their fuel and are incapable to continue burning and keep propelling outwards and so the star collapses on its ownself and then explodes
- White dwarf can collide with a massive star.
- White dwarf can also collide with another white dwarf explode

What are white dwarfs?

A white dwarf is **what stars like the Sun become after they have exhausted their nuclear fuel**. Near the end of its nuclear burning stage, this type of star expels most of its outer material, creating a planetary nebula.

Wein's displacement law:-

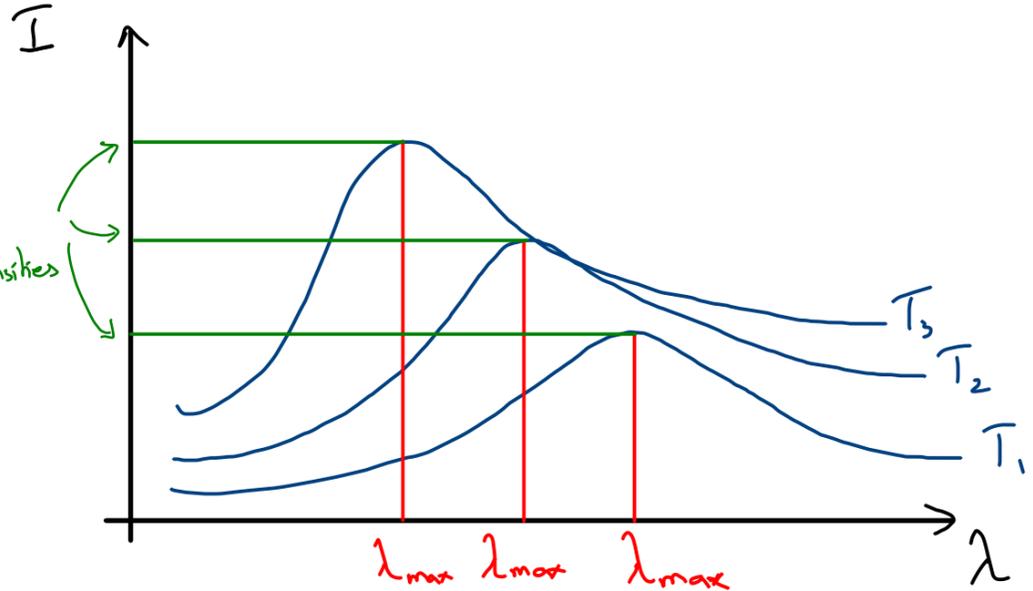
The colour of a star depends on its surface temperature.



Wein's displacement law:-

$$\lambda \propto \frac{1}{T}$$

$$\lambda_1 T_1 = \lambda_2 T_2$$



$$T_1 < T_2 < T_3$$

The peak intensity shifts to lower wavelengths for higher temperatures

Black body radiator:-
 An ideal thermal radiator
 stars are also black body radiators

Stefan Boltzmann law:-

The luminosity of a star is based upon its radius/size and its surface temperature:-

$$L \propto r^2$$

↳ radius of the star

$$L \propto T^4$$

↳ surface temp of a star

$$L = 4\pi\sigma r^2 T^4$$

Stefan-Boltzmann law

$$L = 4\pi\sigma r^2 T^4$$

Stefan-Boltzmann constant

$$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$$

- 12 (a) State what is meant by luminosity of a star.

Total power delivered by a star.

[1]

- (b) The luminosity of the Sun is 3.83×10^{26} W. The distance between the Earth and the Sun is 1.51×10^{11} m.

Calculate the radiant flux intensity F of the Sun at the Earth. Give a unit with your answer.

$$F = \frac{L}{4\pi d^2} = \frac{3.83 \times 10^{26} \text{ W}}{4\pi (1.51 \times 10^{11})^2} = 1336.7$$

$$F = \dots 1340 \dots \text{ unit } \text{Wm}^{-2} \dots [2]$$

- (c) Use data from (b) to calculate the mass that is converted into energy every second in the Sun.

$$L = P = \frac{E}{t} \Rightarrow 3.83 \times 10^{26} = \frac{E}{1} \Rightarrow E = 3.83 \times 10^{26} \text{ J}$$

$$E = mc^2 \Rightarrow 3.83 \times 10^{26} = m (3 \times 10^8)^2$$

$$m = 4.26 \times 10^9$$

$$\text{mass} = \dots 4.26 \times 10^9 \dots \text{ kg } [1]$$

- (d) The radius of the Sun is 6.96×10^8 m.

Show that the temperature T of the surface of the Sun is 5770 K.

$$L = 4\pi \sigma r^2 T^4$$

$$3.83 \times 10^{26} = 4\pi (5.67 \times 10^{-8}) (6.96 \times 10^8)^2 T^4$$

$$\left(\frac{3.83 \times 10^{26}}{4\pi \times (5.67 \times 10^{-8}) (6.96 \times 10^8)^2} \right)^{\frac{1}{4}} = (T^4)^{\frac{1}{4}} [1]$$

$$T = 5771.6 \text{ K} \approx 5770 \text{ K}$$

- (e) The wavelength λ_{max} of light for which the maximum rate of emission occurs from the Sun is 5.00×10^{-7} m.
The temperature of the surface of the star Sirius is 9940 K.

Use information from (d) to determine the wavelength of light for which the maximum rate of emission occurs from Sirius.

$$\lambda_1 T_1 = \lambda_2 T_2$$

$$(5 \times 10^{-7}) (5770) = \lambda_2 (9940) \Rightarrow \lambda_2 = 2.90 \times 10^{-7}$$

$$\text{wavelength} = \dots 2.90 \times 10^{-7} \dots \text{ m } [2]$$

[Total: 7]

12 (a) A star has a luminosity that is known to be 4.8×10^{29} W. A scientist observing this star finds that the radiant flux intensity of light received on Earth from the star is 2.6 nW m^{-2} .

(i) Name the term used to describe an astronomical object that has known luminosity.

Standard Candle / Standard

(ii) Determine the distance of the star from Earth.

$$F = \frac{L}{4\pi d^2} \Rightarrow (2.6 \times 10^{-9}) = \frac{(4.8 \times 10^{29})}{4\pi \times d^2} \Rightarrow d^2 = \frac{(4.8 \times 10^{29})}{4\pi \times (2.6 \times 10^{-9})}$$
$$d = 3.8 \times 10^{18}$$

(b) The Sun has a surface temperature of 5800 K. The wavelength λ_{max} of light for which the maximum rate of emission occurs from the Sun is 500 nm.

The scientist observing the star in (a) finds that the wavelength for which the maximum rate of emission occurs from the star is 430 nm.

(i) Show that the surface temperature of the star in (a) is approximately 6700 K. Explain your reasoning.

Wein's displacement law.

The surface temperature of a star is inversely proportional to λ_{max} (Wein's displacement law)

$$\lambda_1 T_1 = \lambda_2 T_2$$
$$(500)(5800) = (430) T_2 \Rightarrow T_2 = 6744 \text{ K}$$
$$T_2 = 6700 \text{ K}$$

(ii) Use the information in (a) and (b)(i) to determine the radius of the star.

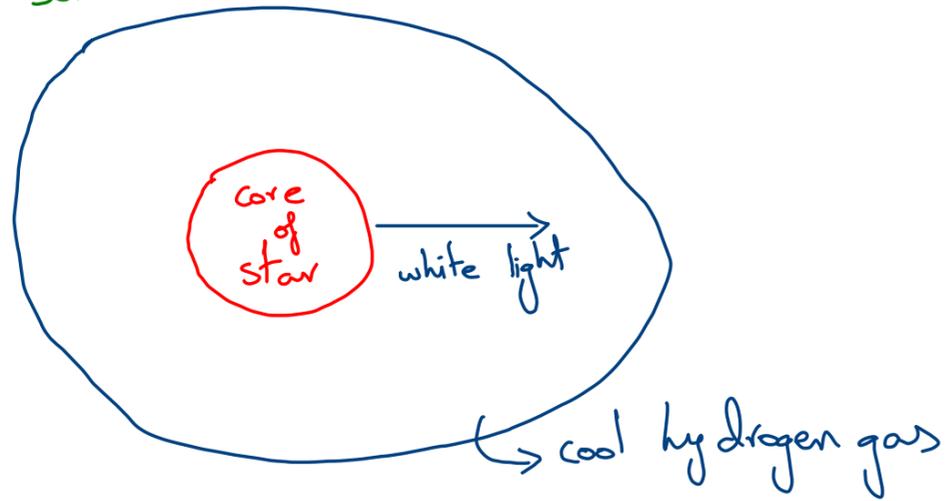
$$L = 4\pi \sigma r^2 T^4$$

$$(4.8 \times 10^{29}) = 4\pi (5.67 \times 10^{-8}) r^2 \times (6700)^4$$

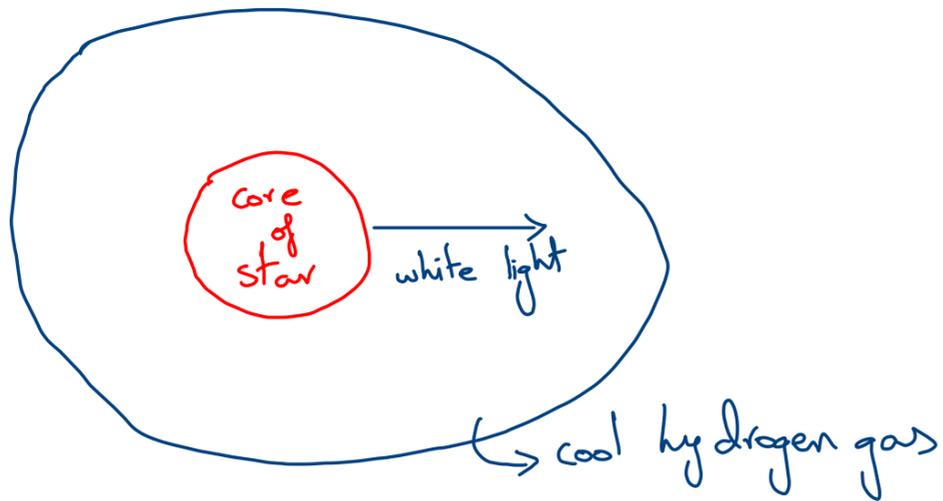
$$r = 1.8 \times 10^{10}$$

Hubble's work:-

Sun



A star far away:-



diffraction grating



diffraction grating



↓ λ shifted to larger wavelengths → redshift

Doppler's effect:-

It is the change in observed frequency due to relative motion between the source and observed

$$f_o = \frac{v}{v \pm v_s} f_s$$

Approach:-
 $f_o \uparrow / \lambda_o \downarrow$

$$v = f \lambda$$

$$f = \frac{v}{\lambda}$$

$$f \propto \frac{1}{\lambda}$$

Separation:-
 $f_o \downarrow / \lambda_o \uparrow$

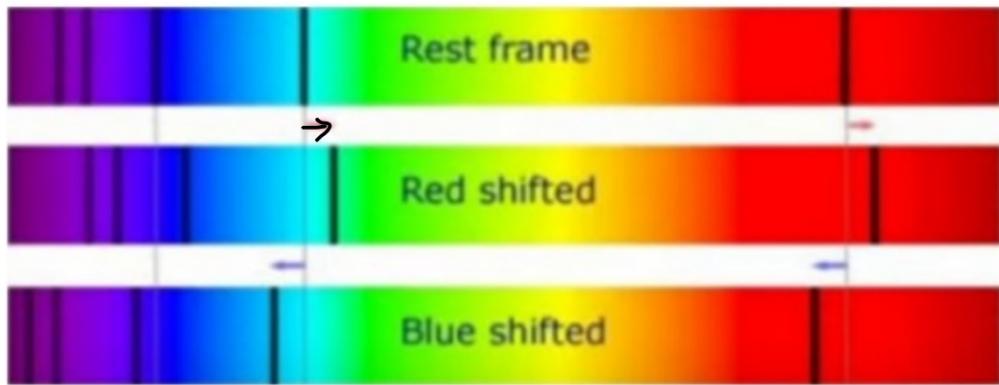
A2 course = $\frac{\Delta \lambda}{\lambda} = \frac{\Delta f}{f} = \frac{v}{c}$

↑ diff in λ of spectral lines

↑ diff in f of spectral lines

→ recession velocity

→ speed of light (3×10^8)



→ lab experiment

→ moving away from us (redshift) → $\lambda \uparrow$

→ moving towards us (blueshift) → $\lambda \downarrow$

1) A particular spectral line in the spectrum of a star is found to have wavelength of 600.80nm compared to 600.00 nm as measured in the laboratory.

What is the velocity of the star? Is it moving towards us or away from the Earth?

600 → 600.80 $\lambda \uparrow$ → redshift → moving away from us

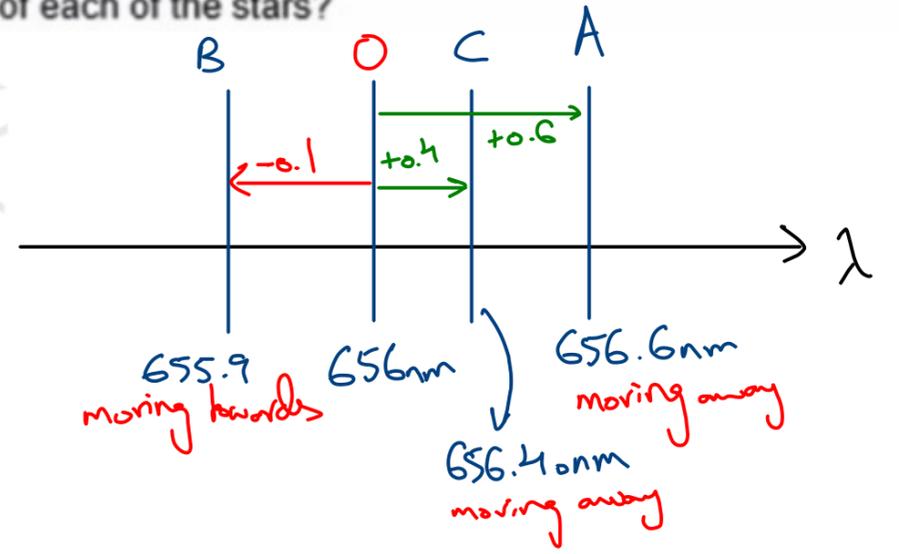
$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

$$\frac{(600.8 - 600) \text{ nm}}{600 \text{ nm}} = \frac{v}{3 \times 10^8}$$

$$v = \frac{(600.8 - 600)}{600} \times 3 \times 10^8 = 400000 \text{ m s}^{-1}$$

The H-alpha emission line in the hydrogen spectrum is 656.0 nm when measured in the laboratory. Star A is observed to have that line at 656.60 nm, star B at 655.90nm and star C at 656.40 nm.

- a) Which star is moving the fastest relative to Earth?
- b) What is the direction of motion of each of the stars?

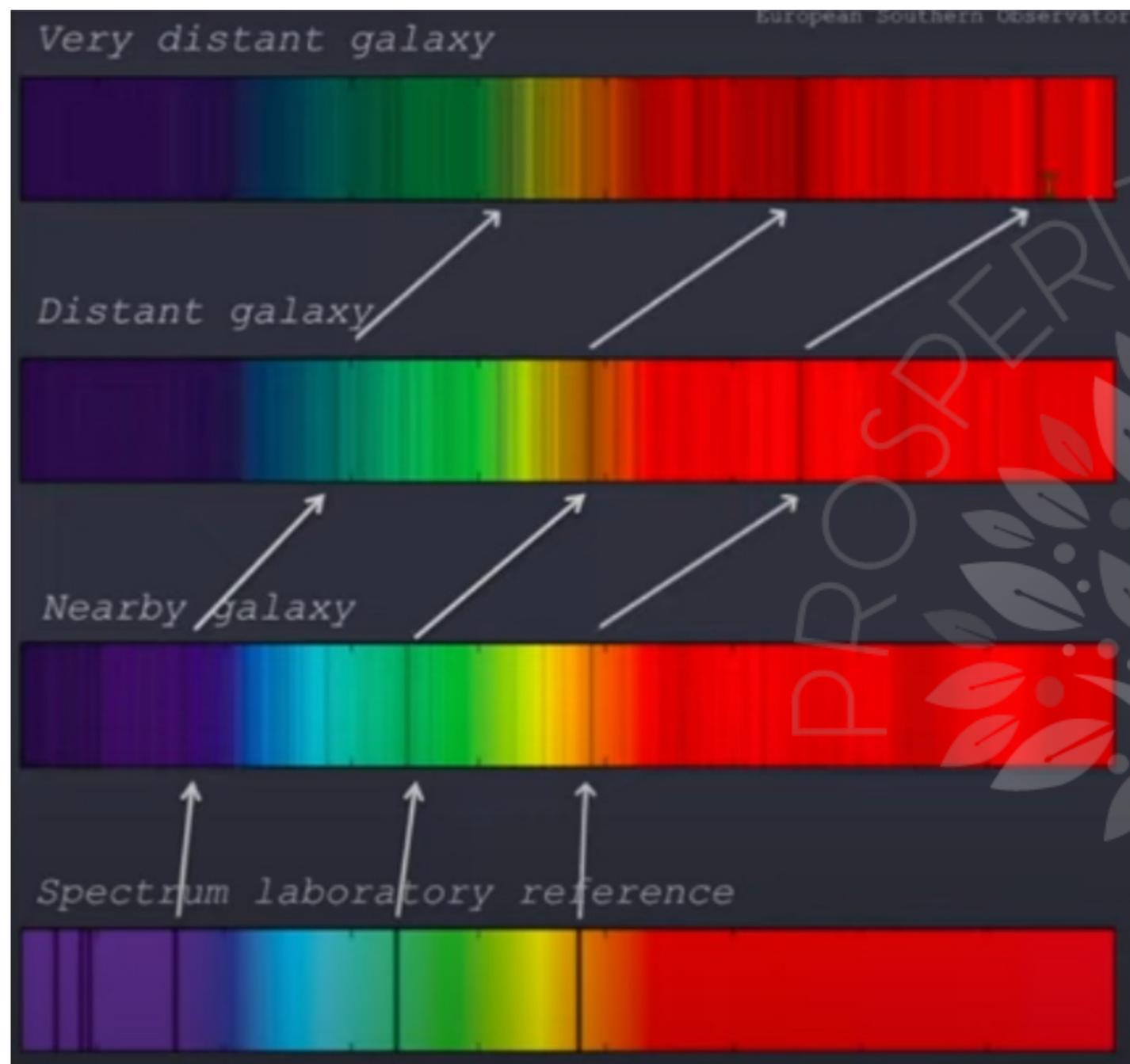


$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

λ const c const

↳ $\uparrow \Delta\lambda \propto v \uparrow$

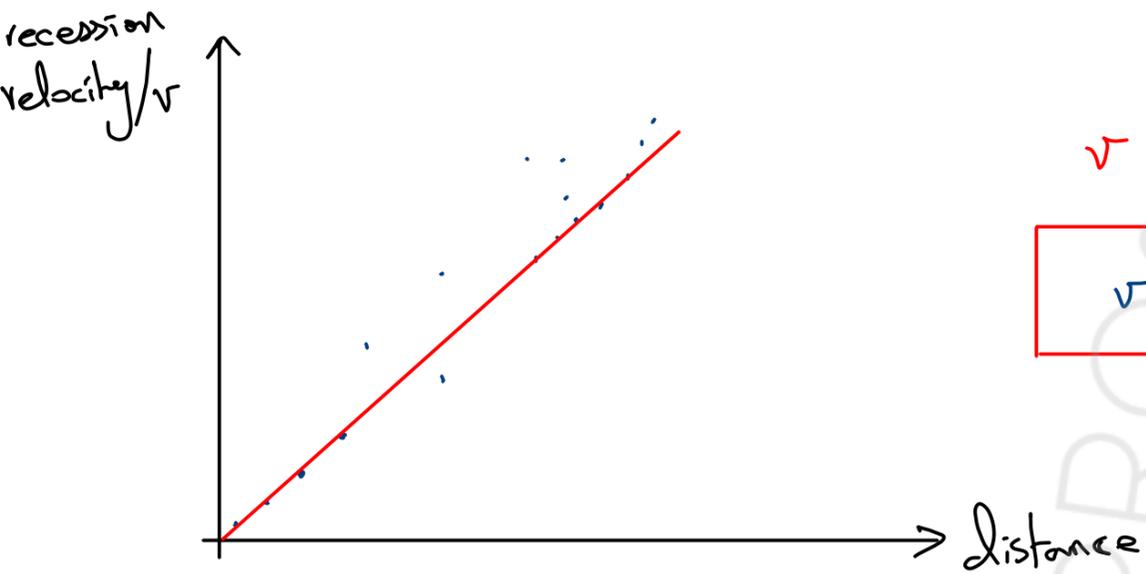
A is moving fastest away from us as its wavelength is most redshifted.



- Most of the spectroms of galaxies are redshifted

- The galaxies that are more distant are moving away with greater speeds (they show more redshift)

Hubble's law:-



$$v \propto d$$
$$v = H_0 d \rightarrow \text{Hubble's law}$$

Hubble's constant (2.21×10^{-18})

- 2) The wavelength of a spectral line in the spectrum of light from a distant galaxy was measured at 398.6 nm. The same line measured in the laboratory has a wavelength of 393.3 nm. Calculate
- the speed of recession of the galaxy
 - the distance to the galaxy.
- (pg347, Oxford Uni Press)

Causes of errors:-

- Galaxies may have rotational motion
- Galaxies recession may be affected by other galaxies
- Maybe the motion of the galaxy is not in the line of sight

$$a) \frac{\Delta \lambda}{\lambda} = \frac{v}{c}$$

$$\frac{393.3 - 398.6}{393.3} = \frac{v}{3 \times 10^8} \Rightarrow v = 4042715$$
$$v = 4.043 \times 10^6$$

$$b) v = H_0 d$$
$$4.043 \times 10^6 = (2.21 \times 10^{-18}) d$$

$$d = 1.829 \times 10^{24}$$

Big bang theory:- **Origin of the universe**

The galaxies that are further away are moving at higher recession speeds

↳ if we reverse time:-

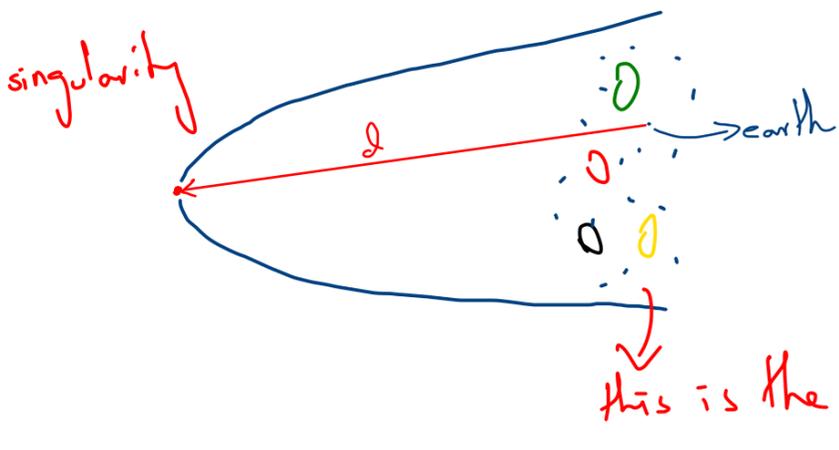
Everything will move inwards and eventually get concentrated in a single point

The big bang theory states that the universe originated from an infinitely dense point known as the singularity and has been expanding ever since.

The Quran also mentions:

"Have those who disbelieved not considered that the heavens and the earth were a joined entity, then We separated them, and made from water every living thing? Then will they not believe?" (Quran 21:30)

Age of the universe:-



$$c = \frac{d}{t} \Rightarrow d = c \times t$$

The age of the universe is still not exactly known as the value of H_0 is prone to the errors in the line of best fit

$$v = H_0 d$$

if we are taking the furthest distance, its recession velocity will be maximum

$$c = H_0 (c \times T_0)$$

↳ age of the universe

$$\rightarrow c = 3 \times 10^8 \text{ (limit of speed)}$$

$$T_0 = \frac{1}{H_0}$$

$$\text{Age of the universe:- } T_0 = \frac{1}{2.21 \times 10^{-18}} = \frac{4.52488 \times 10^{17} \text{ s}}{60 \times 60 \times 24 \times 365} = 1.4348 \times 10^{10} \text{ years}$$

↓
14.3 × 10⁹ years

The universe is 14.3 billion years old.