Astronomy and Cosmology

Astronomy → a discipline that includes study of heavenly bodies, everything except planet earth or everything beyond earth's atmosphere.

Cosmology → a part of astronomy that involves origin/causes/ evolution of universe.

→ the distance b/w sun and earth (centre to centre) is called astronomical unit AU.

$$1\,AU = 1.5 \times 10^{11}\,m$$

→ another unit of distance to ezpress separation b/w heavenly objects is Light year (ly); One ly distance is equal to the distance covered by light (EM radiation) through vacuum in one year.

$$1\,ly = 9.5 \times 10^{15}\,m$$

→ another unit of distance used in astronomy is parsec (pc) which is used to view a distant star from earth.

$$1\,pc = 3.1 \times 10^{16}\,m$$

Luminosity

Stars are identified by the light they emit.
The Luminosity (L) of a star is defined as the total amount of energy emitted per unit time OR the total power of radiation emitted by a star. It is measured in watts or Js^{-1}.

The luminosity of a star depends upon it's size and temperature.

Luminosity → out put power

$$L = \frac{E}{t} \qquad L = \frac{\text{Amount of energy emitted}}{\text{time}}$$

The luminosity of sun is $3.8 \times 10^{26}\,Js^{-1}$. (Approx. $4 \times 10^{26}\,Js^{-1}$)
Stars radiat energy radially in all directions and intensity variation with distance follows inverse square law.

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

$$E = \Delta m c^2$$

$$\Delta m = \frac{E}{c^2}$$

Standard candle

$3.8 \times 10^{26}\,Js^{-1}$

1 standard candle

Standard candle

→ a radiating object of known luminosity e.g. sun.

Standard candle

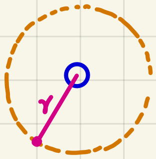
An object of known luminosity is known as standard candle.

The luminosity of sun L_o is 3.8×10^{26} W and it is known as standard candle. It is used as a standard value and used to calculate distances to stars and galaxies.

Any object at temp. above absolute zero radiates and has a luminosity. Its luminosity can be compared with a standard candle.

$$I = \frac{P}{A} = \frac{L}{A}$$

$$I = \frac{L}{4\pi r^2}$$

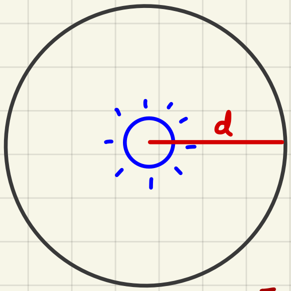


$$I = \frac{L}{4\pi d^2}$$

Intensity

A star emits energy spherically in all directions. The amount of energy incident per unit time per unit area of earth's surface from a star at normal incidence is called Radiant Flux Intensity (F).

$$F = \frac{\text{Amount of energy emitted per unit time}}{\text{Area of sphere}}$$



$\boxed{\frac{E}{tA}}$ Radiant Flux Intensity

$$\boxed{F = \frac{L}{4\pi d^2}}$$

where

Amount of energy emitted by a star per unit time is Luminosity L and d is the distance from centre of the star.

$$F = \frac{E}{tA} = \frac{E/t}{A}$$

$$= \frac{L}{4\pi r^2}$$

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

The radiant flux intensity is measured in Wm^{-2} or $Js^{-1}m^{-2}$.

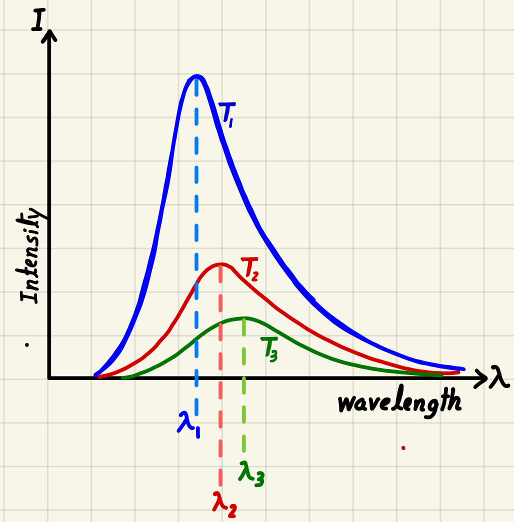
The expression shows that the radiant flux intensity:

* is directly proportional to star's Luminosity
* is inversly proportional to the square of the distance from centre of star (inverse square law)

Stellar Radii

Stars emit radiations/ light due to nuclear reactions and resultant variations of mass. Stars emit different amounts of light per unit time with different wavelengths.
Hence stars differ in colours and brightness.

Stars that appear white to an unaided observer's eye are observed to have different colours when viewed through a telescope as a telescope collects much larger amount of energy.



Radiations emitted by a star has a continuous spectrum of wavelength that includes visible light and infra-red rays also. The intensity of emitted radiation depends upon temperature.

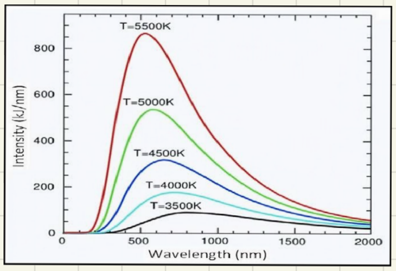
If temperature of a hot object is changed, the distribution of intensity against wavelength changes

$T_1 > T_2 > T_3$

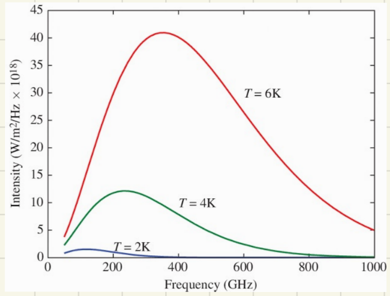
$\lambda_1 < \lambda_2 < \lambda_3$

e.g. if temperature of a star is increased, the emitted radiations have higher intensity at shorter wavelength; more photons of shorter wavelength or more photons of larger amount of energy. $E = \frac{hc}{\lambda}$, $\text{Intensity} = \frac{n}{tA}\frac{hc}{\lambda}$

The curves shown on Intensity – wavelength variation graph are called black body radiation curves.



Black body is defined as an object that absorbs all the radiations incident on it; a perfect absorber. A black body is also a perfect emitter.
Every object emit electromagnetic radiations if it's temperature is above zero Kelvin; absolute zero.



A star can be assumed to be a black body as any radiation incident on it will be absorbed; no reflections or transmissions take place.
The spectrum of thermal radiations emitted by a star has a continuous range of wavelengths with intensity distribution similar to that of a black body radiation curve.

For a black body, different radiation curves are obtained at different temperatures. The peak of each curve is higher at shorter wavelength than the curves at lower temperature.

The laws of thermal radiation are used to analyse the curves.

Wein's Displacement law

The law states that the wavelength of emitted radiations at peak intensity is inversly proportional to the thermodynamic temperature (temp. in kelvin).

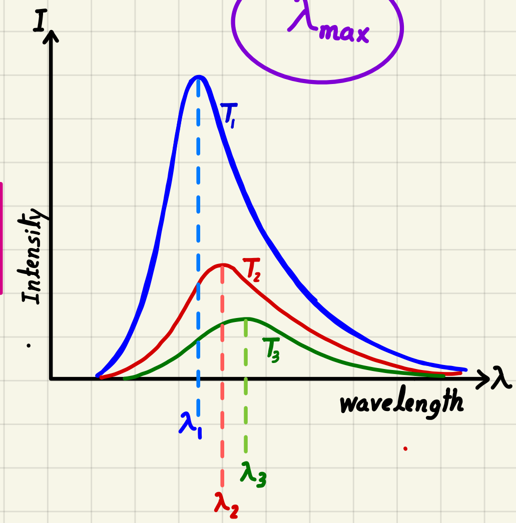
$$\lambda_{max} \propto \frac{1}{T}$$

$\lambda_{max} \longrightarrow$ Wavelength of emitted radiation at maximum intensity

$$\lambda_{max} T = \text{const.}$$

Wein's constant $2.9 \times 10^{-3}\ mK$ (meter, Kelvin)

λ_{max}



The curve shows that at higher temp., the wavelength at peak intensity is shorter.
The wein's displacement law can be used to find temperature of photosphere (surface) of a star by analyzing the radiations from star.

$$T_1 > T_2 > T_3$$
$$\lambda_1 < \lambda_2 < \lambda_3$$

Stafen Boltzman's Law

$$L \propto AT^4$$

$$\frac{L}{A} \propto T^4$$

The law states that the luminosity (or power radiated or energy emitted per unit time) per unit surface area of a black body at a particular temperature is directly proportional to the fourth power of it's temperature.

$$\boxed{\frac{L}{A} \propto T^4 \quad \text{or} \quad \frac{P}{A} \propto T^4}$$

OR

the luminosity of a black body at a particular temperature is directly proportional to its surface area A and the fourth power of its absolute temperature.

$$\boxed{L \propto A T^4}$$

$$\frac{L}{A} = \sigma T^4$$

Stafen Boltzman's constant $5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$

$$\frac{P}{A} \propto T^4$$

Radiant Flux Intensity $F \propto T^4$.

$$\boxed{\begin{aligned} L &= \sigma A T^4 \\ L &= \sigma 4\pi r^2 T^4 \end{aligned}}$$

where
$A = 4\pi r^2$
surface area of sphere

Hubble's Law and Big Bang Theory

Doppler's effect and Red shift

$$f' = \frac{v}{v \pm v_s} f$$

If a source of radiation is travelling relative to an observer, the wavelength (or frequency) of recieved signal is not equal to the actual wavelength of source. The change observed freq. or wavelength is called Doppler shift.

If a source of radiation is moving towards an observer, the wavelength of waves detected must be less than the actual value and vice versa.

If a radiating source like a star or a galaxy is moving away from earth, the wavelengths would be longer than if the star or galaxy was stationary. The spectral lines of emission spectrum of light from galaxy are shifted towards the red part of visible spectrum as wavelength of the light recieved increases.

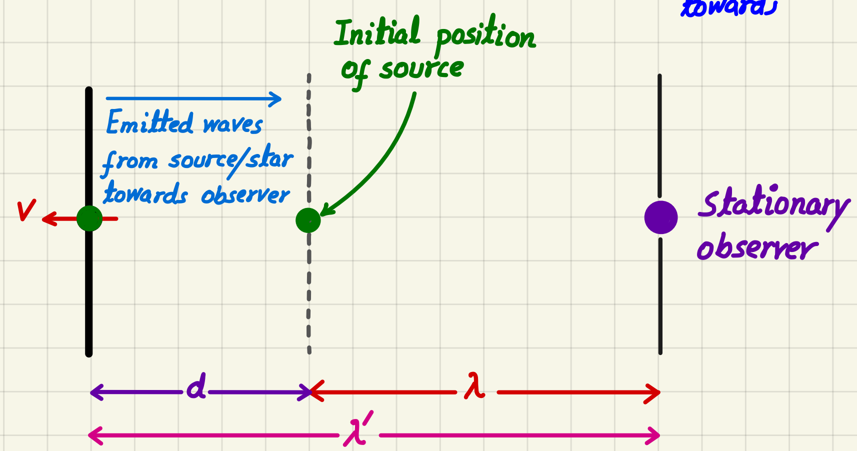
Doppler shift.
- Red shift: Freq. decrease, Source moving away
- Blue shift: Freq increase, Source moving towards

This increase in wavelength due to radiation source moving away (receding) from earth is called Red shift.

$$\lambda' = \lambda + d \qquad \lambda = \frac{c}{f}$$

$$\lambda' - \lambda = d \qquad \lambda = cT$$

$$\lambda' - \lambda = vT$$



$$\frac{\lambda' - \lambda}{\lambda} = \frac{vT}{cT}$$

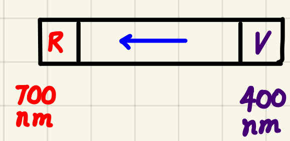
$$\boxed{\frac{\Delta\lambda}{\lambda} = \frac{v}{c}}$$

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

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

- v: Speed of radiation source
- c: speed of light in vacuum
- $\Delta\lambda$: change in apparent wavelength
- λ: Actual wavelength
- Δf: change in apparent wavelength
- f: Actual freq.

When source moves away from a stationary observer, freq. of recieved/detected by observer is less than the actual freq. OR wavelength of recieved signal is greater than actual wavelength;



Red shift
- Increase in wavelength
- Decrease in freq.

Hubble's Law

Edwin Hubble studied continuous expansion of universe by observing light recieved from distant galaxies/stars

It was observed that spectral lines of emmisions from distant stars were red shifted, the wavelengths were elongated.

The red shift observation for different individual stars was used to calculate speed of recession, the speed at which the stars are moving away from earth.

The luminosity of stars was used to estimate the distance of stars from earth

The results of Hubble's observation showed that galaxies are receding from earth at a speed which is directly proportional to the distance from earth.

Hubble's law states that recessional speed of a galaxy is directly proportional to its distance from earth.

$$v \propto d$$

$$v = H_0 d$$

where H_0 represents Hubble's constant.

$H_0 = 2.2 \times 10^{-18} s^{-1}$

The observations showed light/spectral lines recieved from most of the galaxies are red shifted which provides an evidence that galaxies are moving away and have a relative velocity away from earth

The further away the galaxy is, the greater the size of red shift and faster the galaxy is moving.

According to Hubble's law the distant galaxies are moving away from earth. It also shows galaxies are all moving away from each other hence the universe must therefore be expanding. Astronomers believed that the universe was created in a massive explosion and has been expanding ever since. The theory was reffered as Big Bang Theory.

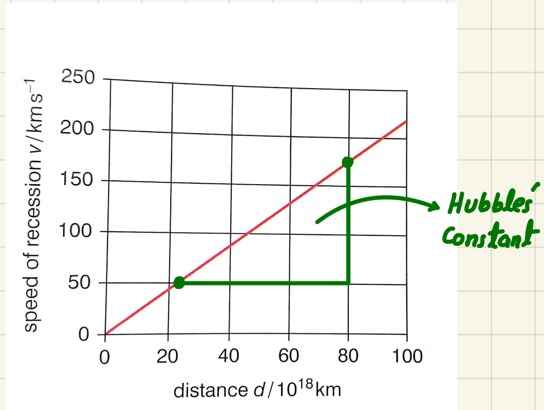
Big Bang Theory

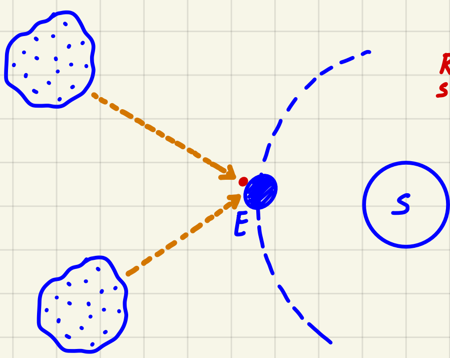
→ Since all distant stars and galaxies are moving away from us; red shifted, the whole universe is expanding.

→ Hubble's law provides the key evidence for the idea of Big Bang theory and the model of expanding universe.

→ Hubble's law suggested that the fabric of space and time is expanding in all directions, such that not only galaxies are moving away from earth but the actual space b/w galaxies is also expanding.

→ Therefore the galaxies that are further away from us move faster than those nearer to us.



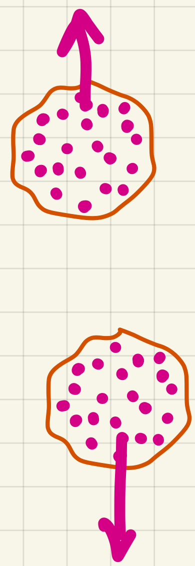


Red shifted
source moving away

$V \propto d$

$$\boxed{\frac{V}{c} = \frac{\Delta\lambda}{\lambda} = \frac{\Delta f}{f}}$$

Big Bang Theory



Luminosity $L = \frac{E}{t}$

Luminosity of sun
$L_o = 3.8 \times 10^{26}\, W$ (1 standard candle)

Radiant Flux Intensity $F = \frac{L}{A}$

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

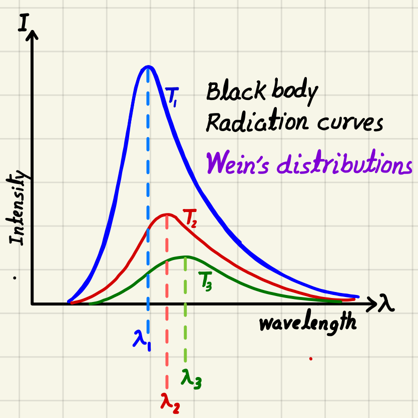
Wein's Displacement law

$$\lambda_{max} = \text{Const.} \frac{1}{T}$$

$$\lambda_{max} T = \text{constant}$$

where const. is $2.9 \times 10^{-3}\, mK$
Wein's constant

$\lambda_{max} \longrightarrow$ Wavelength of emitted radiation at maximum intensity



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Stafen Boltzman's Law

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where
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surface area of sphere

Stafen Boltzman's constant $5.67 \times 10^{-8}\, Wm^{-2}K^{-4}$

Doppler's shift

$$\frac{V}{c} = \frac{\Delta\lambda}{\lambda} = \frac{\Delta f}{f}$$

$V \longrightarrow$ speed of wave source
$c \longrightarrow$ speed of waves

Hubble's Law

$$V \propto d$$

$$V = H_o d$$

where H_o represents Hubble's constant.
$H_o = 2.2 \times 10^{-18}\, s^{-1}$

Q.No. 1. The sun has luminosity of 3.8×10^{26} W and the radiant flux intensity from sun at earth's surface is 1300 Wm^{-2}. Calculate the separation between centres of earth and sun. $F = \frac{L}{4\pi d^2}$

Q.No. 2. Betelgeuse is a star with 1.42×10^{4} standard candles. It's radiant flux intensity at earth is 1.1×10^{-8} Wm^{-2}. How far is Betelgeuse from earth? Standard candle = 3.8×10^{26} W

Q.No. 3. Jupiter's orbit is 5.2 AU from the sun. The Luminosity of Jupiter is 5.09×10^{17} W.
(a) Estimate the standard candles for the Jupiter.
(b) Calculate the maximum radiant flux intensity at earth's surface due to Jupiter's electromagnetic radiation. 1 AU = 1.5×10^{11} m Standard candle = 3.8×10^{26} W

Radiant flux intensity $F = L/4\pi r^2$

Q.No. 4. A star Regulus in the constellation of Leo has apparent brightness of 5.2×10^{-12} that of the sun and luminosity 140 times that of the sun. If the distance from earth to the sun is 1.5×10^{11} m, how far from earth is Regulus?
Standard candle = 3.8×10^{26} W

Q.No. 5. The λ_{max} of radiation from sun is 500 nm when its surface temperature reaches 5800K. The λ_{max} emitted by a nearby star is 310 nm with luminosity of 10 times that of sun. Calculate the steller radius of this star.
$L_o = 3.85 \times 10^{26}$ W (standard candle)

Q.no. 6. A star has a radius of 7×10^{5} Km and temperature of its photosphere is 5800K.
Wein's constant = 2.9×10^{-3}
(a) Calculate the energy radiated by star in one year.
(b) Calculate λ_{max}, wavelength at intensity peak.
(c) The average power recieved on earth per unit area is 130 nWm^{-2}, calculate the distance of this star from earth.