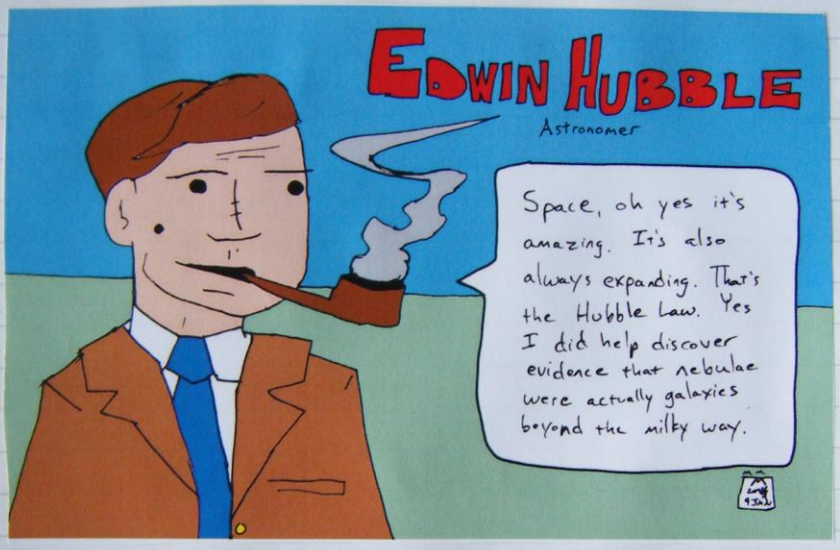
Hubble's Law and the Big Bang - BMcMullen

EDWIN HUBBLE
(USA 1889–1953)



Hubble's Law

In 1929, Edwin Hubble determined that the greater the distance (*d*) a galaxy is from the Earth, the greater the redshift of the light it emitted and therefore the greater the speed (v) at which the galaxy is moving away from the Earth. This suggests that the entire universe is expanding, presumably from an initial explosion called the Big Bang.

Hubble's Law is the simple relationship between a galaxy's distance and speed:

$$v = H_o d$$

where H_o is known as the Hubble constant. The current value of the Hubble constant is about

$2.3 \times 10^{-18}\ s^{-1}$

v = recessional velocity of galaxy
H_0 = Hubble constant
d = distance to galaxy

$$v = H_0 d$$

From $t = \frac{d}{v}$ substitute $v = H_0 d$

$$\Rightarrow t = \frac{d}{H_0 d} \Rightarrow \boxed{t = \frac{1}{H_0}}$$

We can then estimate the age of the Universe using this equation where:

$$t = \frac{1}{2.3 \times 10^{-18}} = 4.35 \times 10^{17} \text{ s}$$

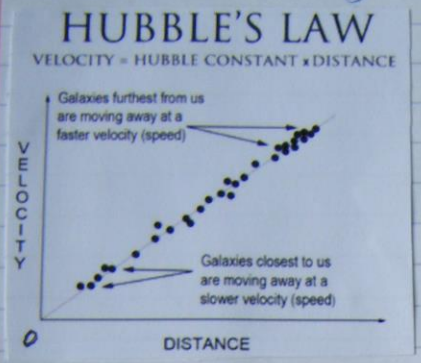
∴ To convert seconds into years

$$\Rightarrow \frac{4.35 \times 10^{17}}{60 \times 60 \times 24 \times 365} \approx 1.37 \times 10^{10} \text{ years}$$

$$\approx 13.7 \times 10^{9} \text{ years} \approx \boxed{13.7 \text{ billion years}}$$

Hubble's constant has been modified over the years due to improvements in the accuracy of astronomical measurements from astronomical telescopes.

Hubble's Law graph



In summary

- The further away that a galaxy is from us the faster the speed that it is travelling at.

- Hubble's Law tells us that the Universe is continually expanding.
- Hubble's law can be used to find the age of the Universe.

The assumption made here is that the Universe is expanding at a constant rate.

Converting light years into metres.

Astronomical distances are measured in Light years. Where one light year is the distance travelled by light in one year.

$d = ?$

$v = 3 \times 10^8 ms^{-1}$

$t = 1 \times 365 \times 24 \times 60 \times 60$

$\therefore t = 31,536,000s$

$d = vxt = 3 \times 10^8 \times 31,536,000$

$\Rightarrow d = 9.46 \times 10^{15} m$

Ex1

Q A distant galaxy has a recessional velocity away from Earth of $5.8 \times 10^6 ms^{-1}$.

Calculate the distance from Earth to the galaxy using Hubble's Law in Light years (Ly).

A $V = 5.8 \times 10^6 ms^{-1}$
$H_0 = 2.3 \times 10^{-18} s^{-1}$
$d = ?$

- $V = H_0 d$

$$\Rightarrow d = \frac{V}{H_0} = \frac{5.8 \times 10^6}{2.3 \times 10^{-18}}$$

$$\Rightarrow d = 2.52 \times 10^{24} m$$

$9.46 \times 10^{15} m \rightarrow 1$ Light year

$$\therefore 2.52 \times 10^{24} m \rightarrow \frac{2.52 \times 10^{24}}{9.46 \times 10^{15}} = 2.66 \times 10^8 Ly$$

Ex2

Q A distant star is moving away from Earth. Calculate the recessional velocity of the star when it is 4.59×10^7 Ly away from Earth.

A
- $4.59 \times 10^7 Ly = 4.59 \times 10^7 \times 9.46 \times 10^{15} m$
$= 4.34 \times 10^{23} m$

- $V = H_0 d \Rightarrow V = 2.3 \times 10^{-18} \times 4.34 \times 10^{23}$

$$\Rightarrow V = 9.98 \times 10^5 ms^{-1}$$

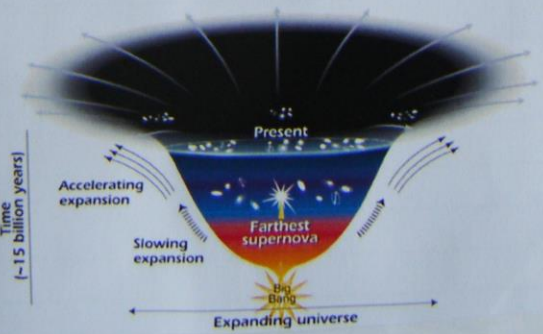
(5).

Big Bang Theory

Big Bang Theory - Evidence for the Theory

What are the major evidences which support the Big Bang theory?

1. First of all, we are reasonably certain that the universe had a beginning.
2. Second, galaxies appear to be moving away from us at speeds proportional to their distance. This is called "Hubble's Law," named after Edwin Hubble (1889-1953) who discovered this phenomenon in 1929. This observation supports the expansion of the universe and suggests that the universe was once compacted.
3. Third, if the universe was initially very, very hot as the Big Bang suggests, we should be able to find some remnant of this heat. In 1965, Radioastronomers Arno Penzias and Robert Wilson discovered a 2.725 degree Kelvin (-454.765 degree Fahrenheit, -270.425 degree Celsius) Cosmic Microwave Background radiation (CMB) which pervades the observable universe. This is thought to be the remnant which scientists were looking for. Penzias and Wilson shared in the 1978 Nobel Prize for Physics for their discovery.
4. Finally, the abundance of the "light elements" Hydrogen and Helium found in the observable universe are thought to support the Big Bang model of origins.



If the Universe is expanding, why can't I find a parking space?

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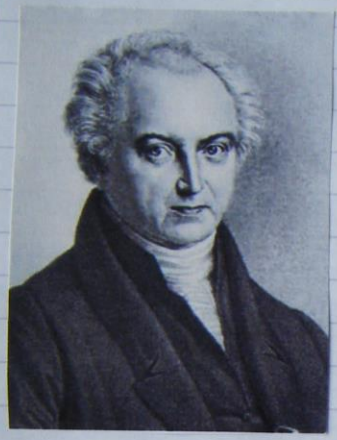
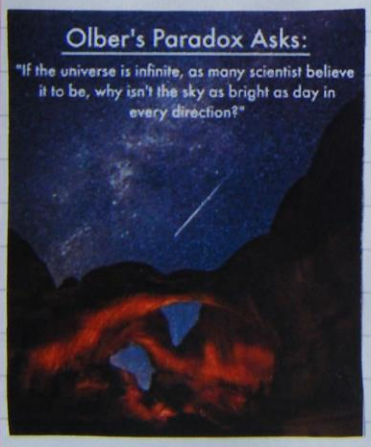
Olber's Paradox



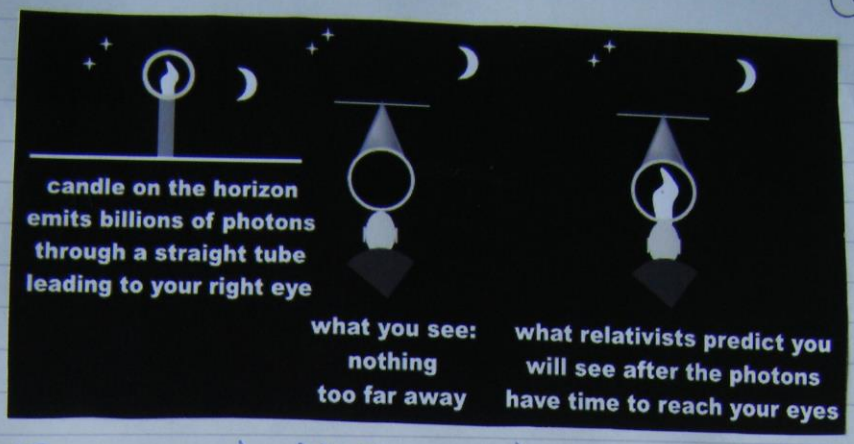
HEINRICH WILHELM OLBERS (GERMANY 1758-1840)



In the sky at night we have areas of light (stars) and dark (nothing).

If the Universe was not expanding then everywhere you looked in the sky would be of even brightness.

However the universe is expanding with the stars moving very quickly. So much so that their light is red-shifted out of the visible spectrum and cannot be seen.



In an infinite universe a star will be visible along any line of sight. This is providing that there has been time for the light to reach us. This means that the universe cannot be infinite and must have a beginning.

Blackbody Radiation

A blackbody is an object which absorbs all of the radiation that is incident on it and then radiates energy which is dependant on the object itself.

The temperature of the object will determine the radiation emitted.

We observe stars on Earth which emit electromagnetic radiation.

The frequency of the electromagnetic radiation emitted is directly proportional to the energy of the radiation.

* $E = hf$

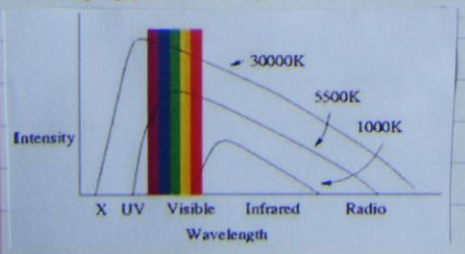
- E: Energy of the radiation (J)
- h: Planck's constant (6.63×10^{-34} Js)
- f: frequency of the radiation (Hz)

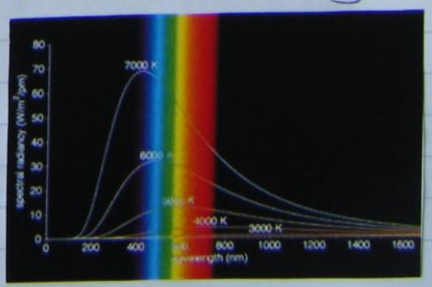
This is looked at in great depth in the Particles and Waves unit.

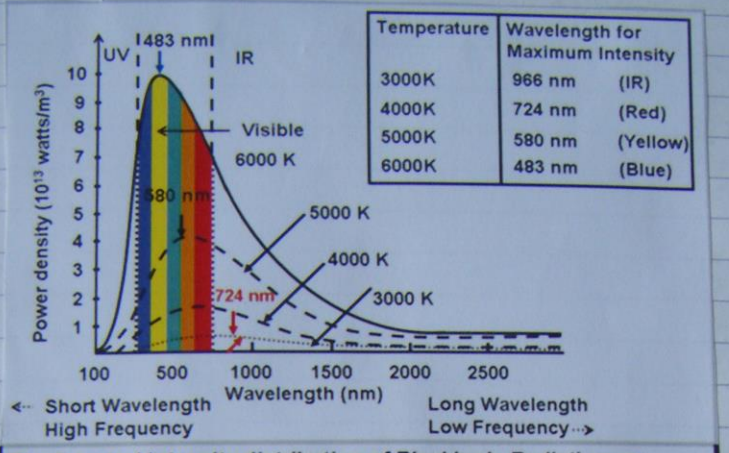
The temperature of a star can be worked out by

- Thermal energy emitted which is related to
- The relative amount of each type of radiation emitted by the star.

The radiation Irradiance against the wavelength of the radiation curve for a star displays the same shape of curve as a 'black body radiator'.





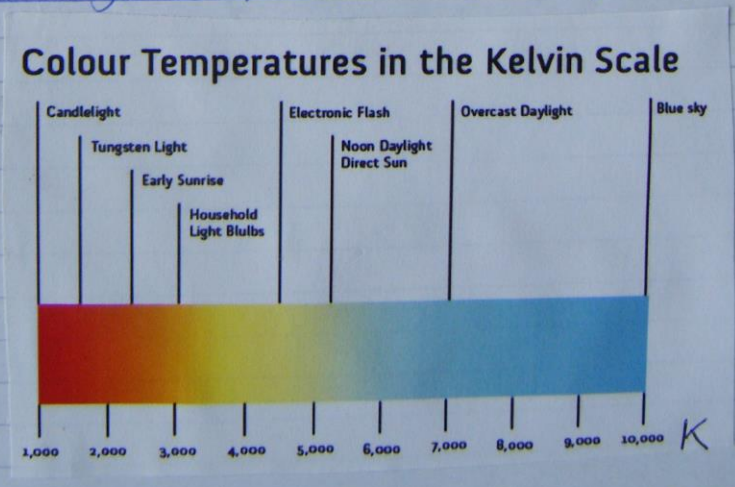


Temperature	Wavelength for Maximum Intensity	
3000K	966 nm	(IR)
4000K	724 nm	(Red)
5000K	580 nm	(Yellow)
6000K	483 nm	(Blue)

Fig. Spectral intensity distribution of Blackbody Radiation vs Wavelength Intensity Maximum shifts to shorter wavelengths as temperature increases.

- Higher temperatures are related to high thermal energies and thus lower peak wavelengths.
- Hotter stars emit higher thermal energies and will have a greater area under the curve.

Putting temperature into perspective



Surface temperatures of stars

Stars glow with different colours when they are examined closely with powerful telescopes. From a distance stars appear as white specs of light in the night sky when viewed by the naked eye.

Wien's Displacement law

The theory of blackbody radiators can be applied to stars although stars themselves are not perfect blackbody radiators.

Wien showed that the the peak wavelength of light emitted by a star multiplied by the surface temperature of a star is constant.

$$\lambda_{PEAK} \times T = 2{\cdot}898 \times 10^{-3}\ m\ K$$

Kelvin

λ_{PEAK}: Peak Wavelength of light emitted from a star

T: Surface temperature of a star

metres

CONCLUSION

The greater the surface temperature the lower the peak wavelength of the light emitted by the star.

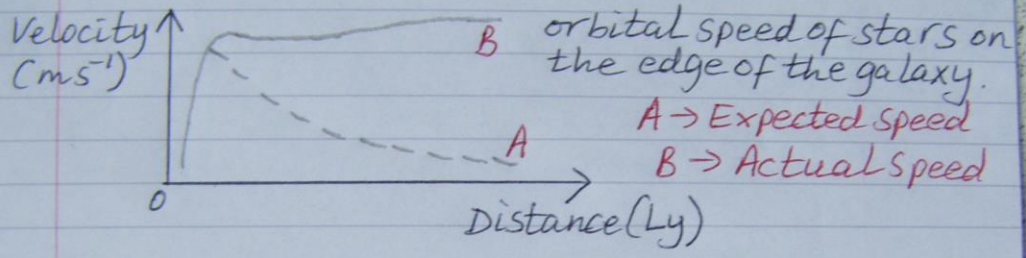
ie Star giving off violet light ⇒ high temp

Star giving off red light ⇒ low temp

Dark Matter

This is matter that exists in our Universe but it cannot be seen. It is invisible to astronomers who use telescopes which detect different forms of electromagnetic radiation.

It is thought that 23% of the Universe is made up of dark matter.



It was found that stars on the edge of the galaxy were travelling at speeds much greater than expected and were defying Newton's Law of gravitation.

The conclusion was that there was additional mass in the galaxy that we could not observe from Earth.

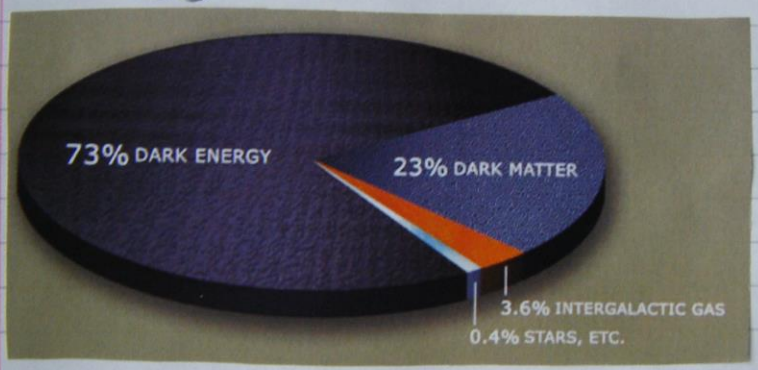
This additional mass provided the extra gravitational attraction which allows the stars to maintain their velocity.

Dark Energy

This is related to the rate at which the universe is expanding.

It cannot be detected like dark matter with electromagnetic radiation sensors.

It is thought that 73% of the Universe is made up from dark energy.

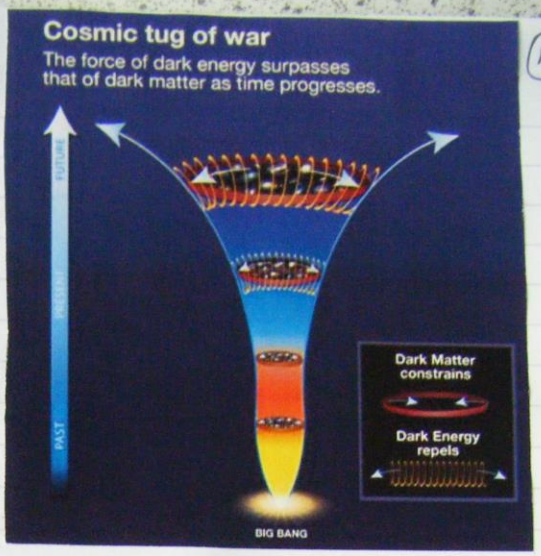


Contents of the Universe.

It is thought that the rate at which the Universe is expanding is increasing. This is happening at a greater rate than expected by Hubble's Law.
This would suggest that there must be some form of energy source driving the expansion.

Dark matter
v
Dark Energy
through
time.

13



Star Life cycles

Astronomers have studied the life cycle of stars from their birth to their death.

The sequence of events occuring can be plotted on a Hertzsprung-Russell diagram. (An H-R diagram)

When plotting temperature and luminosity patterns appear which are related to:

- type of star (H → He main sequence in the core of the star.)
- radius of the star
- age of the star

H-R diagram