COSMOLOGY

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Cosmology is a branch of Physics that studies -

(1) The large scale structure of the Universe.

(2) The way in which the Universe changes in time.

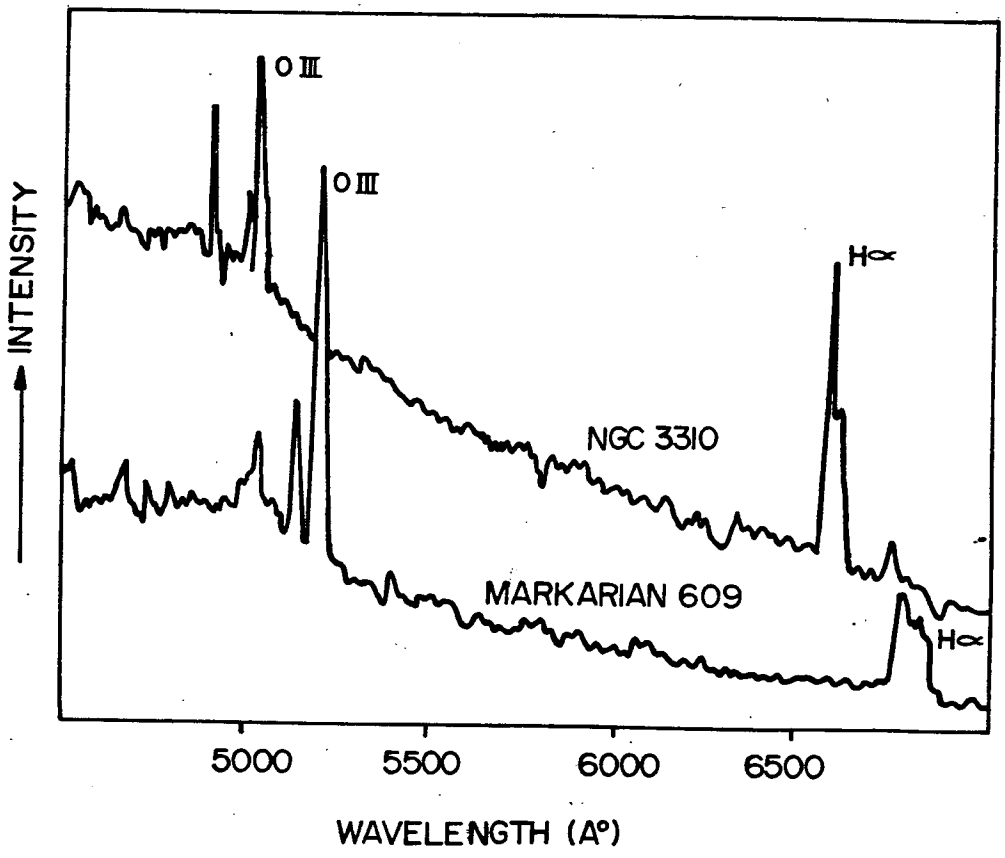
(3) The origin of Space, Time and Mattter.

Modern Cosmology began in the 1920s with the work of Edwin Hubble.

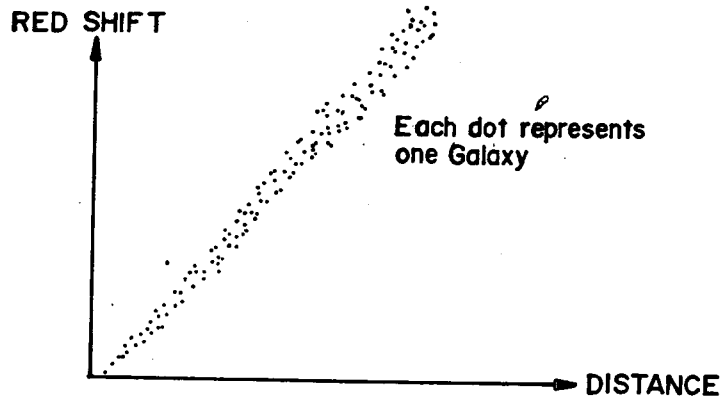
THE HUBBLE LAW

In the 1920's Edwin Hubble examined the spectra of several thousand Galaxies. He made a revolutionary discovery.

SPECTRA OF TWO GALAXIES :-



The spectral lines of the more distant Galaxy (Markarian 609) are shifted to longer wavelengths, i.o. they are "Red Shifted". The "Hubble Law" shows a relationship between Red Shift and Distance:-



THE HUBBLE LAW

Definition of Red Shift :-

$$z = \frac{\Delta\lambda}{\lambda}$$

Where -

λ = Wavelength of emission line

$\Delta\lambda$ = Amount by which line is shifted

If an object is moving away from the observer at high speed then it's spectral lines will also be Redshifted by amount Z

$$Z = \frac{\Delta\lambda}{\lambda} = \sqrt{\frac{1 + \frac{V}{c}}{1 - \frac{V}{c}}} - 1$$

Where -

V = Velocity of object

C = Speed of light

For the reason, the Redshift of light from distant Galaxies shows that the Universe is expanding. The Hubble Law states that more distant Galaxies are moving more quickly away from us. Their locity Of Recession" (v^-) is given by :-

$$V^- = H_o \cdot d$$

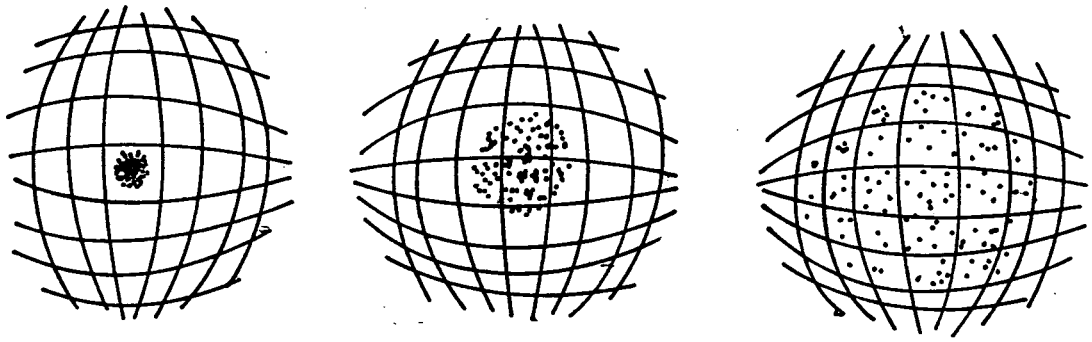
d = distance (measured in Megaparsecs, MPC)

Ho = Hubble constant whose value is not exactly known but somewhere between 50-100 kms^{-1} MPC^{-1}

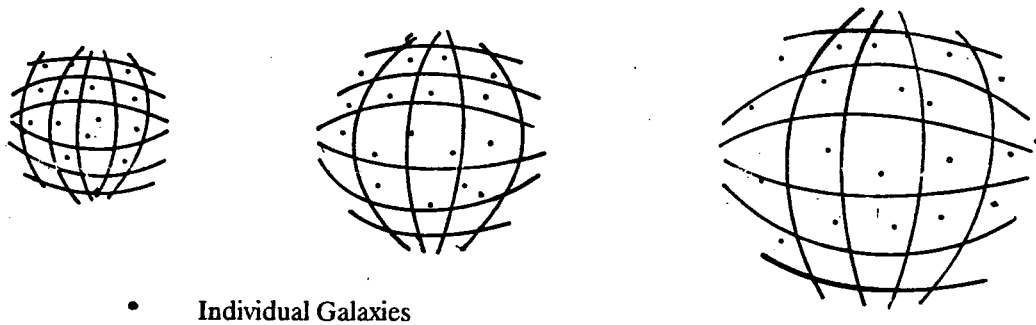
EXPANSION OF THE UNIVERSE

This can be thought of in two ways,

WRONG X



RIGHT ✓



• Individual Galaxies

Space

As the Galaxies move away from each other they do not expand into a Pre-existing space (top picture). Instead, space itself expands and carries the Galaxies with it. Redshifts are therefore cavsed by the expansion of space "Stretching" light waves to longer wavelengths.

THE BIG BANG THEORY

If space is expanding, there must have been a time when it had zero size. The event at the beginning of the expansion is called the big bang. The, space and matter were created in this event.

The age of the universe can be calculated from the Hubble constant Ho.

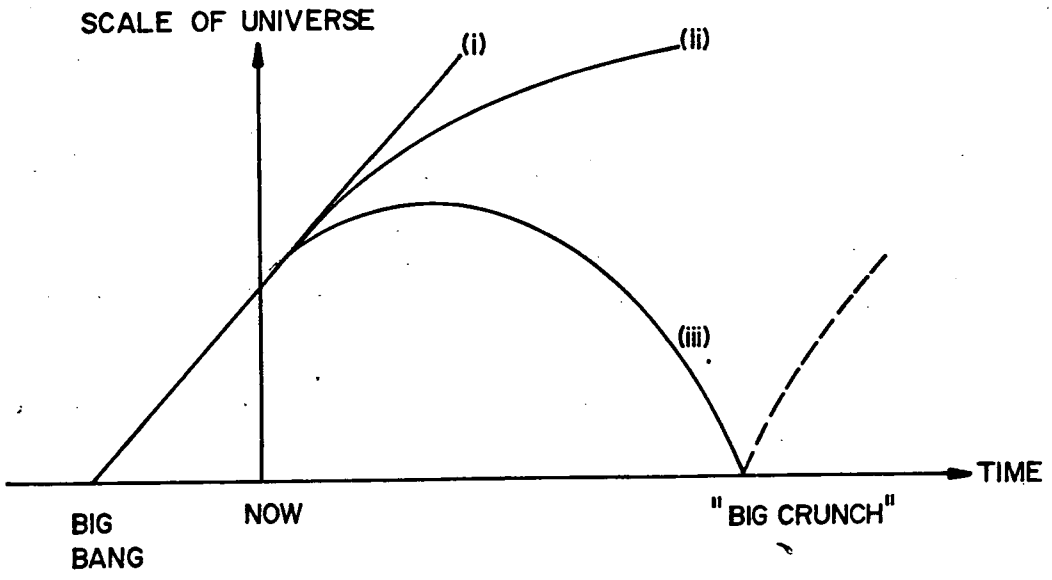
$$\text{Age} \simeq \frac{2}{3} Ho^{-1} \simeq 15 \text{ billion years.}$$

The force of gravity between the Galaxies causes the value of Ho to change: the expansion is slowed down in the distant future there are 3 possible cutcomes -

(1) The expansion continues forever.

(2) The expansion continues but at an ever decreasing rate.

(3) The force of gravity stops the expansion and causes the Universe to contract to zero size.



THE FATE OF THE UNIVERSE

Whether the Universe continues to expand or eventually contracts to a big crunch depends on the density of matter.

ρm_o = Critical Density

$$= \frac{3 H_o^2}{8G}$$ (G = Gravitational constant)

If the average density of the Universe is $> \rho m_o$ then it will eventually contract. If it is $< \rho m_o$ then the Universe will expand forever.

ρm_o is very low, equals to 5 atoms of hydrogen per $100m^3$ of space.

The actual average density of visible matter in the Universe is $= \rho m_o / 25$ which implies that the Universe will expand forever.

Some recent discoveries show that visible matter may only be a small fraction of the total matter in the Universe. Many Astronomers believe that the actual density $= \rho$ exactly and that the Universe will expand forever at an ever decreasing rate.

Most of the mater in the Universe is unseen "DARK MATTER". We know it is there only because of it's gravitational attraction. It's composition is unknown, another great mystery of cosmology.

THE VERY EARLY UNIVERSE

The first 10^{-43} seconds after the big bang cannot be described by Physics. The density and temperature were so high that modern Physics theories do not work.

$t = 10^{-12}$ S

The Universe has expanded and coolled to 10^{15} Kelvin.

$t = 10^{-6}$ S

The temperature = 10^{13}K. The Universe is a hot dense ball of protons, neutrons, electrons, positrons, photons and neutrinos. They are continually colliding and interacting.

t = 1 S

Temperature = 10^{10}K. The density is so low that the neutrinos no longer interact with the other particles.

t = 15 S

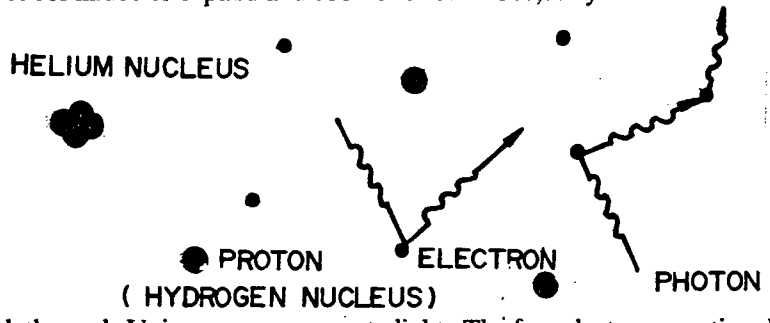
Temperature = 3 Billion K. The electrons and positrons combine to form photons. A small excess of electrons remains.

t = 1 minute - 5 minutes

Some protons and neutrons combine in nuclear fusion reactions to form Devterium, Helium and Lithium. The temperature is similar to the core of a massive star : 1 Billion K.

THE EARLY UNIVERSE

After 5 minutes the Universe is a hot ionised gas containing 76% Hydrogen, 24% Helium and small amounts of Deuterium, Lithium. It continued to expand and cool for another 500,000 years.

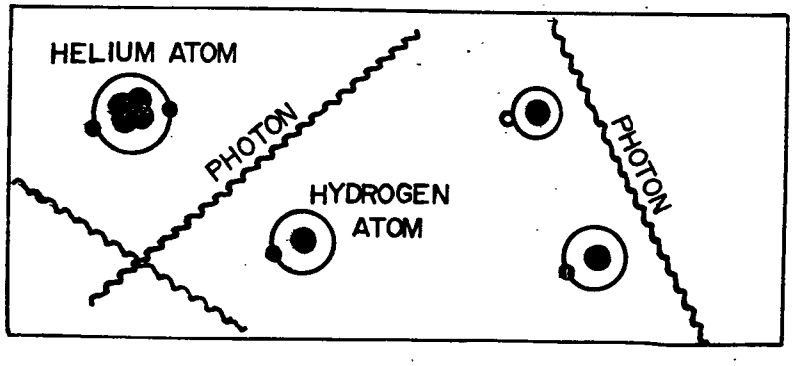


Because it was ionised, the early Universe was opaque to light. The free electrons continually interacted with photons.

t = 500,000 years

The temperature had now fallen to 3000K and the electrons and nuclei combined to form atoms. Photons could then pass freely through space without being absorbed. Light and Matter became

de - coupled. These photons are visible today coming from every direction in space.



The expansion of space has Redshifted the photons to the wave part of the spectrum. They constitute the cosmic microwave background.

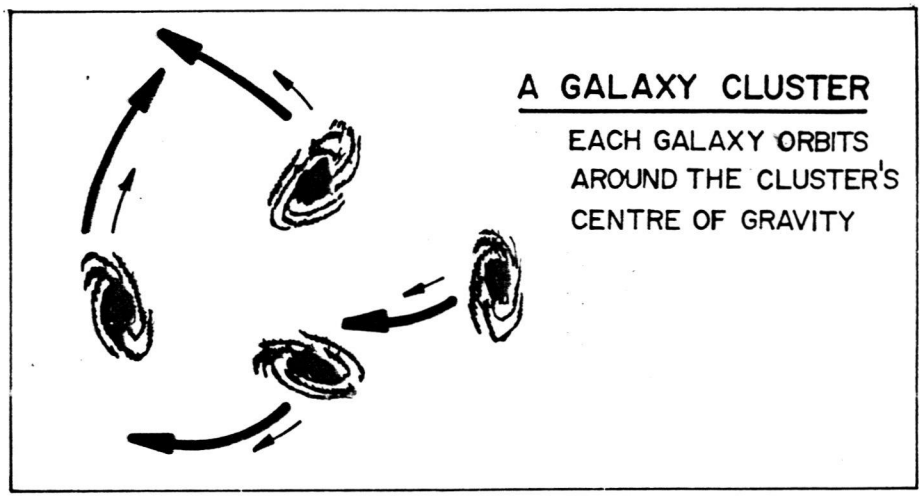
DARK MATTER - 1

There is much evidence for the existence of Dark Matter.

Example (1)

Calculate Velocity

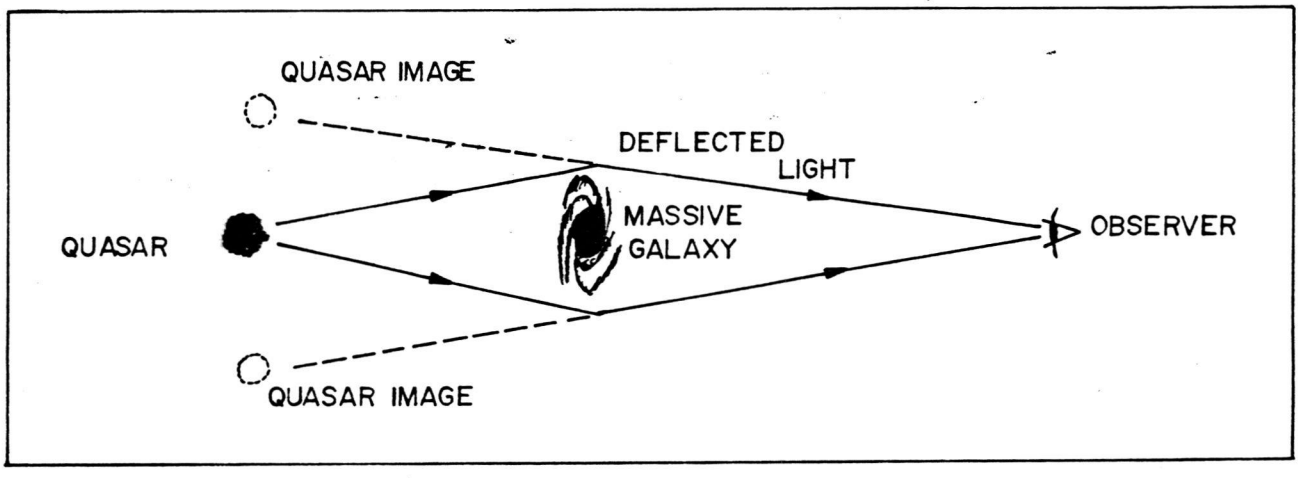
Actual Velocity



If we observe the orbital motions of Galaxies in clusters, we find that their orbital velocities are too high. The clusters must contain unseen matter.

Example (2)

Light from distant objects such as quasars can be deflected by the gravity of less distant Galaxies.



Double or Multiple images of the Quasar can be produced. The Quasar can even appear as a ring surrounding the Galaxy.

By measuring the deflection angle it is possible to weigh the Galaxy and show the presence of Dark Matter.

DARK MATTER - 2

The evidence for Dark Matter suggests that the density of matter in the Universe is $\geq \frac{m_o}{5}$

The normal matter of stars, nebula and planets is called Baryonic matter. It is composed almost entirely of protons and neutrons. A certain fraction of Dark Matter is Baryonic and may be in the form of,

Very hot intergalactic gas

Massive planets

Brown Dwarf stars

Black Holes

An even larger proportion of Dark Matter (at least 75%) must be non-baryonic. It may be composed of sub-atomic particles as yet unknown to science. Possible candidates for this non-baryonic matter are,

Weakly interacting massive particles (WIMPs)

Axions (theoretical particles)

Mini Black Holes

Neutrions

Quark Nuggets (theoretical)

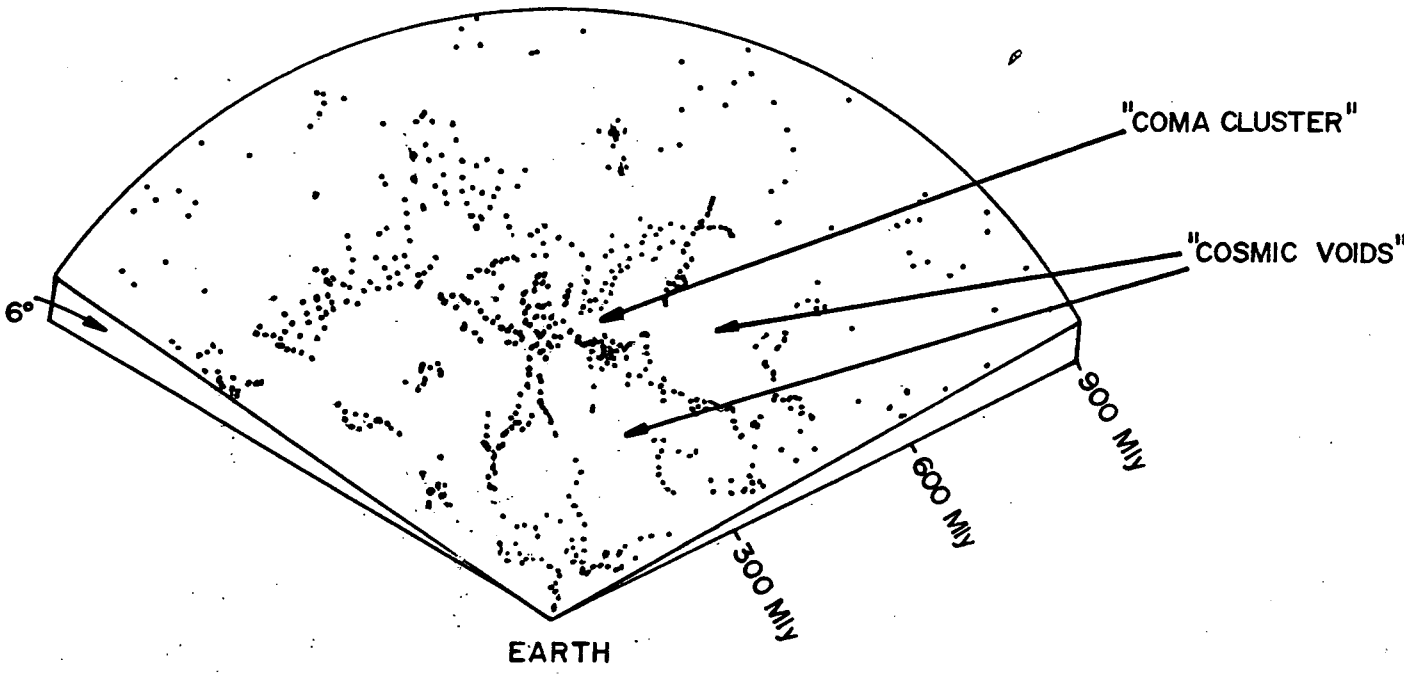
The problem in explaining the nature of this dark matter is often called - "MISSING MASS PROBLEM". It's solution is a large area of study in modern cosmology.

MYSTERIES OF COSMOLOGY

The cosmic background explorer (cobe) catellite showed that the cosmic microwave background was very isotropec (smooth). This shows that matter in the early Universe was evenly distributed.

Recently, very distant obkects called quasars have been observed with Redshift Z = 4.9. Because they are so distant their light has taken 85% of the age of the Universe to reach us. Astronomers cannot explain how quasars formed so quickly after the big bang if the matter in the Universe was so smooth.

The diagram below shows the positions of Galaxies in one small strip of sky :-



The Galaxies are arranged into "Filaments". Huge volumes of space contain NO Galaxies. These are called cosmic voids. These large scale structures should not exist because of the smoothness of the early Universe. Their origin is unknown.