Cosmology

The study of the structure and evolution of the universe

Cosmological Principle : except for local irregularities, the universe should look the same for all observers. [The universe is homogeneous and isotropic.]

Perfect cosmological principle : except for local irregularities, the universe should look the same for all observers at all times.

Large scale structure of the universe - what does the universe look like?

- Geocentric model
  - sun, moon, 5 planets, stars embedded in crystalline, concentric spheres
  - music of the spheres

- Copernican Revolution
  - heliocentric model but circular orbits of planets

- Galileo : resolved the Milky Way into stars

- William Herschel : made star counts; proposed a sun centered Milky Way

- Speculations by philosophers (Immanuel Kant) : we live on "island universes"

- Kapteyn Universe : ellipsoidal stellar distribution with the sun close to the center

- Harlow Shapley : center of the Milky Way in the direction of the constellation Sagittarius; determined sun's position in the Galaxy.

- Edwin Hubble : proved the existence of external galaxies and studied the distribution of galaxies. His conclusion : "Thus the observable region is not only isotropic but homogeneous as well - it is much the same everywhere and in all directions."

- George Abell and Fritz Zwicky : studied and catalogued clusters of galaxies.

- Harlow Shapley - realized that clusters of galaxies were also clustered - metagalaxy.

- Revival of the concept of a hierarchical universe by european astronomers (Charlier, Lundmark, Holmberg).

- Gerard de Vaucouleurs : proved that we belonged to the Local Supercluster which is a flat system of clusters of galaxies.

- Subsequent studies showed that superclusters are real and not due to a chance fluctuation in the number density of galaxies.

- Is the universe homogeneous or hierarchical? If the universe is homogeneous then it should be characterized by an average density. But there is Carpenter's relation : Larger a cluster of galaxies, the smaller is its density. [Note : Larger the cluster, the greater the M/L.]

- Statistical studies indicate scale lengths (sizes)

10 Kpc	galaxies
100 Kpc	pairs + multiplets
1 Mpc	groups + clusters
10 Mpc	superclusters
100 Mpc	third order clusters

-Density contrast decreases with scale lengths. At scale length of 1000 Mpc the universe is homogeneous.

- What is the structure of the "building blocks" of the universe

1) Galaxies : elliptical, lenticular, spiral, irregular
2) Structure of clusters

L F

cD B

C I

cD : supergiant elliptical at center
B (binary) : two supergiant galaxies
L : 3 or more bright galaxies in a line (plane)
C (core-halo) : bright galaxies near the center
F (flat) : galaxies in a flat system
I : irregularly distributed

3) Structure of superclusters - no symmetry, some are disk-like and others are filamentary

Arrangement of superclusters : galaxies arranged on the surface of bubble-like structures diameters 25 to 50 Mpc. The universe appears "spongy".

Cosmological Models

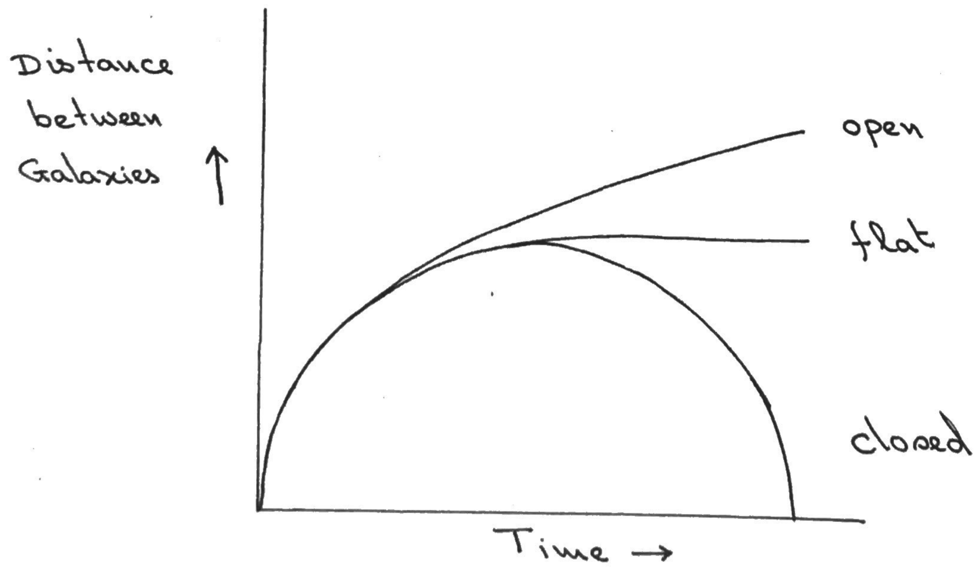
1) Steady State Model : The universe is infinite and eternal. The density remains constant. Matter is created continuously to keep density constant in an expanding universe.
Problem : Cannot explain the microwave background radiation

2) Big Bang Model : The universe had a beginning in time [~15 billion years ago]. The initial explosion caused the expansion of the universe. The original radiation cooled down and exists as the microwave background radiation.

3) Oscillatory Universe Model : The universe will expand, halt, and then contract. It will go through the cycles of expansion and contraction ad infinitum.

Fate of the Universe

1) Open : The universe will expand forever.
2) Closed : The expansion will eventually be halted by gravitational forces and will reverse itself. The universe will contract back to a single point.
3) Flat : The outward expansion is exactly balanced by the gravitational forces. The expansion will halt but not reverse itself.

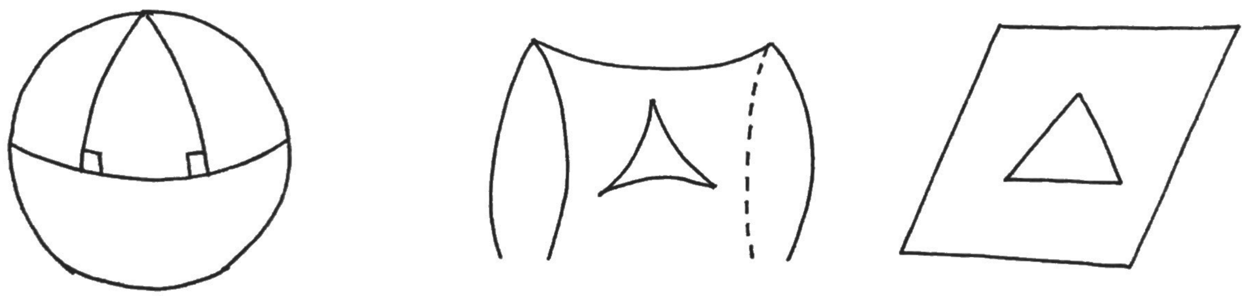


<u>Geometry of the Universe</u>

1) Spherical : Positive curvature (surface of a sphere). Closed Universe. Sum of angles in a triangle > 180°.

2) Hyperbolic : Negative curvature (surface of a saddle). Open Universe. Sum of angles in a triangle < 180°.

3) Flat (Euclidean) : Zero curvature. Flat Universe. Sum of angles in a triangle = 180°.



- Evolution of the universe is determined by the critical density ρ_c

$\rho_c = (3 H_o^2) / (8 \pi G)$ where H_o is the value of the Hubble's constant for the present epoch. The critical density for the present epoch is 10^{-30} gm /cm^3.

If ρ_o is the present density of the universe then let us define the quantity $\Omega_o = \rho_o/\rho_c$

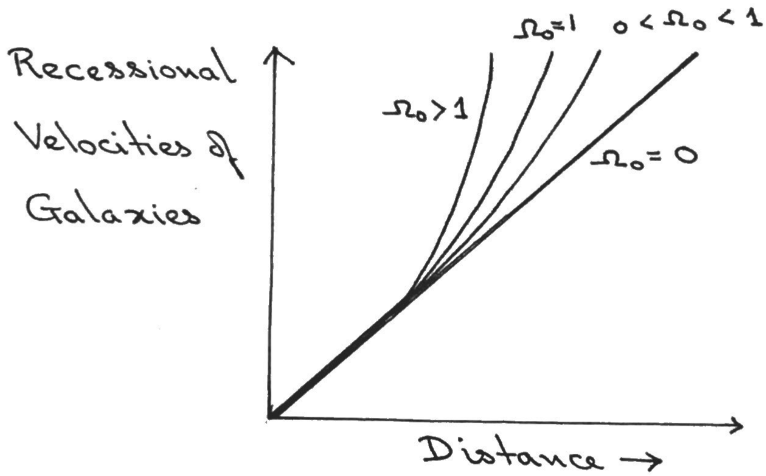
1) Open universe :	$\rho_o < \rho_c$,	$\Omega_o < 1$
2) Closed universe :	$\rho_o > \rho_c$,	$\Omega_o > 1$
3) Flat universe :	$\rho_o = \rho_c$,	$\Omega_o = 1$

- The average density of the luminous matter we see is $\approx 3 \times 10^{-31}$ gm / cm^3 [i.e. $\rho_o < \rho_c$]. The value is uncertain because of dark matter in the universe.

- Deceleration of the universe : The rate at which the expansion is slowing down.

$\Omega_o = 0$,	empty universe
$0 < \Omega_o < 1$,	open universe, small deceleration
$\Omega_o = 1$,	flat universe
$\Omega_o > 1$,	closed universe, large deceleration

Observations favor open universe (?)



- Primordial abundance of light elements :

Light elements deuterium (^2H) and Lithium (^7Li) produced during the early stages of the Big Bang. Higher the primordial mass density smaller is the amount of ^2H and ^7Li produced. Primordial mass density is related to present day deceleration. The abundance of deuterium in old PopII stars is high implying low primordial mass density. Hence small amount of deceleration. Indicates the universe is open. ^7Li results are similar.