The Big Bang Theory

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Abstract:

We did a survey at our current understanding of the universe, in particular the Big Band Theory.

I. **Introduction**:

We have divided our research into different parts:

i) Review of classical mechanics

~ gravitation field and the gravitational potential energy

ii) Review of basic assumptions in cosmology

~ the cosmological principle (homogeneity and isotropy of the universe)

iii)The Big Bang theory

~ the content of Big Bang Theory

~ the observations that support Big Band Theory

- redshifts of the galaxy (Hubble's law)

- cosmic background radiation

- the abundance of light elements H, He, Li

~ what beyonds Big Bang theory

- the formation of galaxy and stars have not been explained

~ questions arose from the theory

- the flatness problem

iv) Different possible universes

~ closed universe

~ open universe

~ flat universe

~ the citical density of the universe

v) The end of our universe

~ big crunch

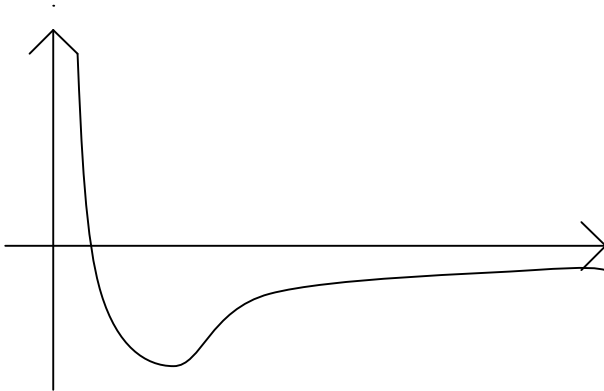II. **Review of classical mechanics** ~ gravitation field and potential energy

Gravitation force between a star and a planet:

$F = g (Mm/r^2)$ M: mass of star,   m: mass of planet

r: distance between the centers of two masses

g: gravitational constant

Corresponding Potential Energy Vs   r (y against x)

(Notice the existence of repulsive force when 2 stars touch each other)

Classically, Escape velocity $= \sqrt{2GM/R}$,

$\Rightarrow$ When M is too large and R too small, the escape velocity is so large that even light **cannot** escape $=>$ black hole

III. Review of basic assumptions in cosmology

Basic assumptions:

Homogeneity of universe
- large scale distribution of matter is uniform
- related to conservation of linear momentum in classical mechanics under the Noether's theorem
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Isoropy of universe
- large scale distribution of matter is isotropic
- related to conservation of angular momentum in classical mechanics

These two assumptions together are called Cosmological Priniciple.
The major consequence of cosmological priniciple is that the universe has no edge and no centre.

IV. Current picture of our unoiverse - Big Band Theory

(a) The expansion of the universe and Doppler effect
Edwin Hubble's 1929 observation that galaxies were generally receding from us provided the first clue that the Big Bang Theory may be right.

How do we know that the galaxies are receding - Doppler's effect:
When a source is receding from us, the observed spectra is red shifted. The amount of red shift is measured by $Z = $ (frequency emitted/ frequency observed)$^{-1}$

(b) Some basic observations:

1) Hubble's Law
- It was deduced from the Doppler shift of distant Galaxies that the velocity of a distant galaxy moving away from us is proportional to its distance from us.
- Therefore, we conclude that the universe is expanding uniformly
$V = H \times r$, where H = Hubble's constant ~ 50-100 km/secMPc, r = Distance of galaxy from us and V = velocity
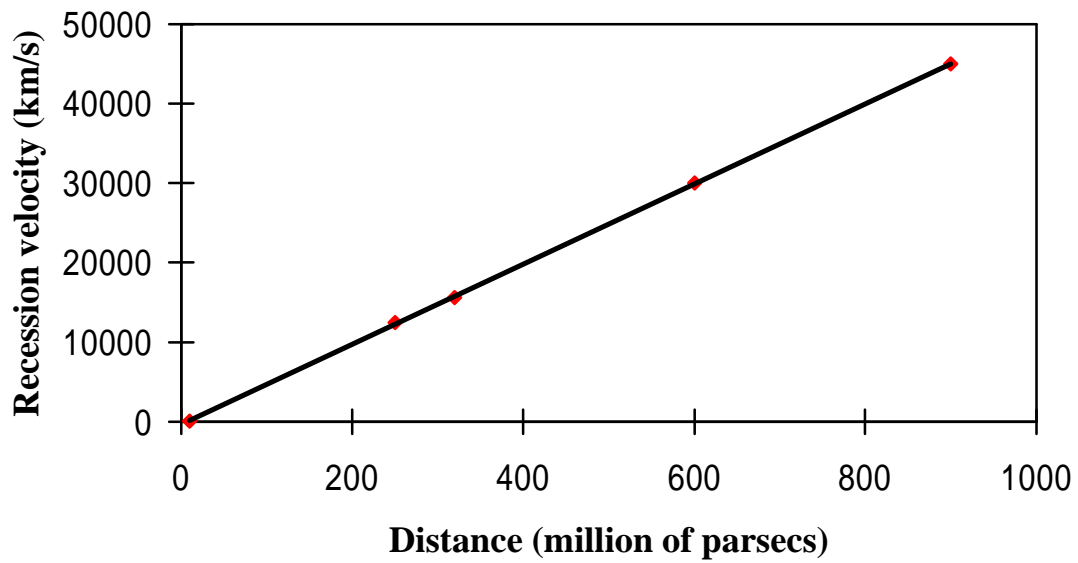
For the visible universe, we assume that at the edge of the universe, the galaxies are moving at almost the speed of light. So we put v=c, then, c = H x maximum r.
We know c and H, therefore we can estimate as the size of the universe.

2) Microwave background radiation
    - Noise in electromagnetic spectrum (cosmic microwaves) is observed to come from all directions. It was radiation from the farthest reaches of our universe. The microwaves were remarkably uniform which illustrated the homogeneity at the early stages of our universe!

Fluctuations of the microwaves observed by COBE satellite:
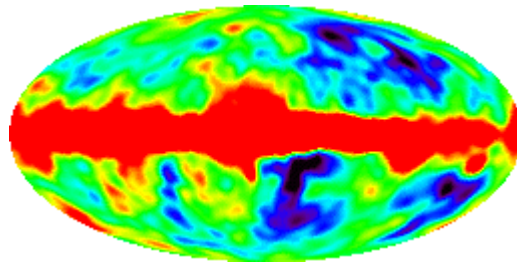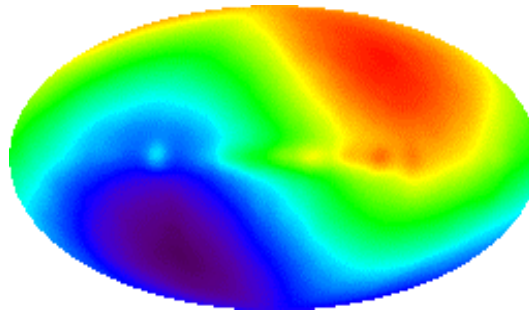
(c) Different kinds of universe

From general relativity, matter induces curvature of spacetime through their mass and large mass implies more curvature in spacetime. According to General Relativity, there are several possible states of universes:

1) Closed universe:

- When mass of universe > critical mass, spacetime will develop a positive curvature (like surface of a sphere). The universe will expand slowly until it finally stops (imagine an expanding baloon) $\Rightarrow$ Big Crunch
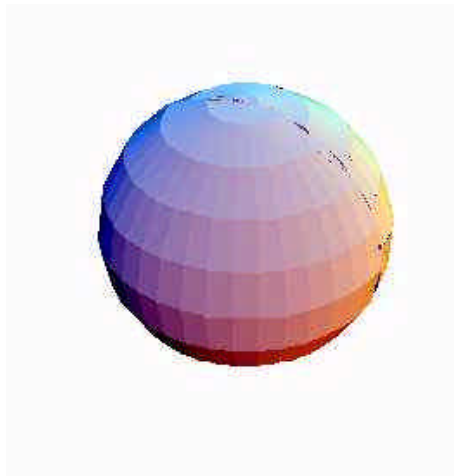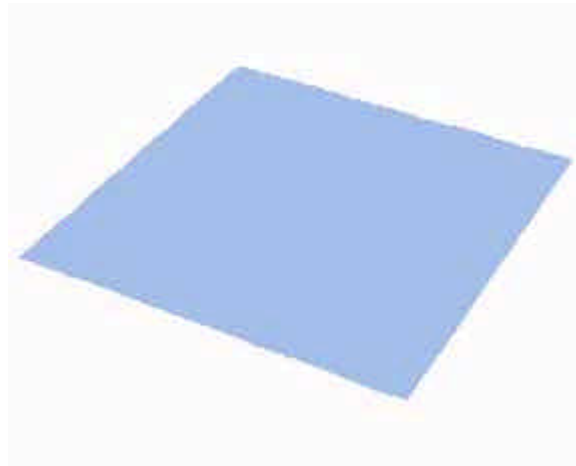
2) Open universe:

- When mass of universe <critical mass, spacetime will develop a negative curvature (like a horse saddle). The universe will expand forever ⇒ Infinite Universe
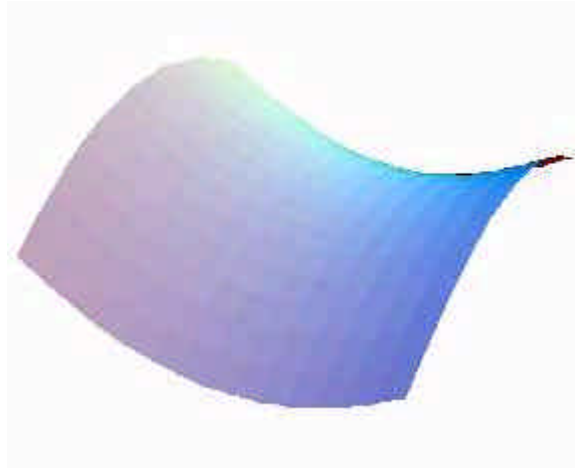
3) Flat universe:

- When mass of universe = critical mass, spacetime has no curvature. The universe expand slowly but the expansion continues forever

What is Big Bang?

- If we trace the Hubble expansion back in time, we conclude
    1). All matters in the universe should be in a very small volume long time ago:
    if we trace back to t =0, the size of the universe is zero!
    2). At t =0, all matters must be compressed into zero size

The universe close to Big Bang (For time 0<t<0.0001 second)

- Universe is filled with high energy photons
- Temperature is high, about 1012K
- Density is high about 1013g/cc
- Few massive particles that interact continuously with photons
- High energy photons create particle and *antiparticles pairs*

Matter Universe:
 Matter (hadrons and leptons) dominates our universe. As universe expands, temperature decreases! An important question in cosmology is, how does matter form?

- Matter creation scenario:

First 3 minutes
- Protons, neutrons and electrons are produced within the first few seconds
- Photons interact with the charged particles
- By the first three minutes
  Proton + neutron deuterium (heavy hydrogen) $\Rightarrow$ Formation of light nuclei

First 30 minutes of Creation
- Nuclear reactions stopped and we have matters in form of Helium (about 25%) and Hydrogen & Deuterium (about 75%).
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First 1 million years
- Temperature cools down to 3000K
- Nuclei recombine with electrons to form atoms
- Universe becomes transparent
- Matter dominated Universe results

V.   The End of our Universe

The Critical matter density is *4×10-30g/cc* from General Relativity and a boundary between open and closed universes exist at this density. The future of our universe depends on the actually matter density of our universe. If the matter density of our

universe > critical density ➔ closed universe and a Big Crunch. On the other hand, If matter density of our universe < critical density ➔ we have an open universe that will expand forever. If matter density = critical density ➔ we have a flat universe that expands, but the expansion rate will slow down.

What is the situation with our Universe?

- Our observed matter density is about 10% of the critical density.
- However it is discovered that there exists *dark matter* in our universe (see below) that should be counted also.
- The present evidences in total suggests *we have an open or flat universe*.

Dark Matter:

Dark matters are matters that do not emit light. So they are difficult to see. Their existence is inferred from their gravitational effect; for example, from the rotation of observed galaxies. When dark matter exists in front of a star, there is twisting of light emitted from the star.

Beyond Big Band theory:

➢ Why is our universe so close to be flat?
➢ Suppose there is small deviation from flat universe at creation, this deviation will be magnified significantly during Hubble expansion, so that our present universe cannot be so flat.

When the universe was very young and hot, 4 forces (Gravitational, Electromagnetic, Weak and Strong forces) were indistinguishable (unified field theory). As the universe began to expand and cool, the symmetry is broken and triggered a sudden inflation in the size of universe!

Inflation of the universe solves the flatness problem. Take a balloon as example. If the balloon expands in size, to an ant on the balloon surface, the balloon looks perfectly flat when the expansion was over..

During the period of inflation, the universe expanded enormously at a very short time, about 10^3s. Then it resumed its earlier expansion, except that the size of the universe

was about 10^{50} larger than it was before.

➢ It does not explain why the universe is so uniform on the very largest scale, but is so non-uniform on smaller scales.
➢ The Big Bang Theory makes no attempt to explain how structures like stars and galaxies came to exist in the universe!

Estimation of matter density in our universe

We believe that total energy is conserved, E =K.E.+ P.E.
$= 1/2\ Mv^2 - GM^2/R \sim 0$ (M ~ mass of universe, R ~ radius of universe)

v = HR (by Hubble's law)

$\Rightarrow 1/2\ H^2 R^2 - GM/R$

$\Rightarrow 1/2\ H^2 R^2 \sim G\ (\rho\ 4\pi R^3/3)/R$

$\Rightarrow 1/2\ H^2 R^2 \sim G \rho\ 4\pi R^2/3$

$\Rightarrow \rho \sim 3H^2/8\pi G$

If $\rho > \rho$ critical, M increases
Then gravitational force strength increases and leads to Big Crunch.
If $\rho < \rho$ critical, M decreases
Then gravitational force strength decreases and leads to forever expansion.

Big Crunch

♦ Big Bang at t = 0, universe expands and then contracts till the Big Crunch
♦ Nothing can say after Big Crunch because that should be the end of the Universe
♦ The Big Crunch is another singular point in the evolution of universe.
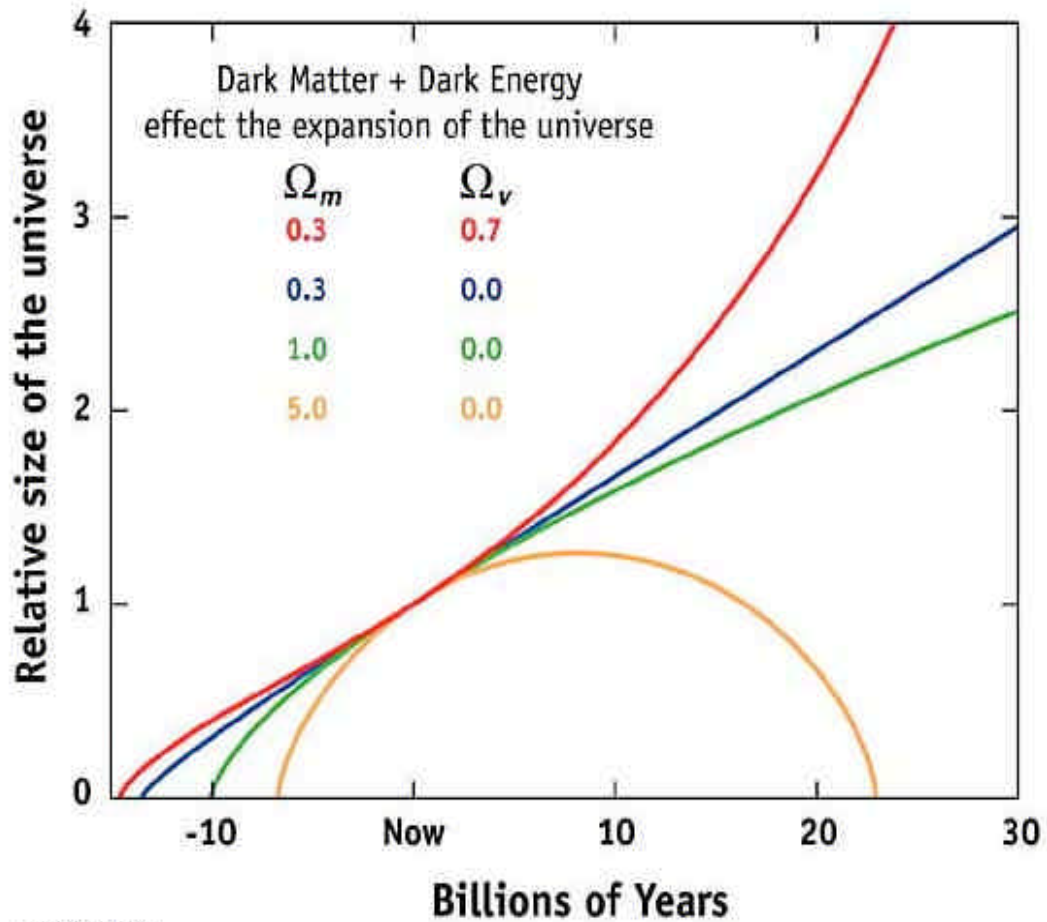
Orange ~ closed, high density universe that has expanded for several billion years

Green ~ flat, critical density universe

Blue ~ open, low density universe (expansion slows down)

Red ~ large fraction of the matter in the universe is in form dubbed "dark energy"
      which speeds up expansion.