An Introduction to Expanding Universe

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From metaphysics to science

Universe is very fascinating. Does it have an origin?, an end?; whether it is static or evolving, all these questions are once thought to be metaphysical. But today we are able to give very logical answers to most of these questions, with the advent of General Theory of Relativity (by Einstein) and advancement in observational techniques.

1. 1665 Newton - Theory of Grvaity
2. 1916 Eisntein - General Relativity or Modified theory of gravity.
3. 1917 Einstein - Universe is static (cosmological constant)
4. 1922-A Friedmann -Predicting Expanding Universe.
5. 1927 - G Lamatre - Predicting and supports expanding universe
6. 1929 Edwin Hubble - Universe is expanding
7. 1934 - Dark matter - Zwicky
8. 1948 Alpher, Bethe and Gamow - Synthesis light elements
9. 1948 - Gamow - Cosmic Microwave Background Radiation - predicted.
10. 1965 - CMBR - discovered by Pezias and Wilson
11. 1990 - CMBR has black body spectrum characteristics (COBE) staelliet
12. 1992 - Fluctuations in CMBR tempertaure - reason for structure formation - COBE
13. 1998 - Accelerated expansion of the universe and Dark energy

Salient features

- The universe began with the Big Bang, and is estimated to be approximately 13.7 billion ($\pm$ 130 million) years old
- Infaltionary epoch - accelerated expansion (not due to dark energy) - last few seconds
- Radiation dominated phase - decelerating phase
- Matter dominated phase - decelerating phase
- Dark energy dominated phase - Accelerating Phase
- Light nuclei like $H, He, ...$ were formed (starts within the first three minutes - take around three weeks)
- Radiation were decoupled
- Structures were formed in the matter dominated era.

Why we believe in the theory of expanding Universe.

- Unierse is expanding - Predicted by Friedmann in 1922
- Verified - Hubble in 1929
- CMBR - the background radiation - Predicted by Gamow
- Verified - Penzias and Wilson in 1965
- Abundance (amount) of light elements - 75% of H, 24% of He, 1% of rest of the elements - Prediceted by Alpher, Bethe and Gamow in 1948
- Verified in 1970

Expanding Universe

- Galaxies or clusters - Basic building blocks of the universe.
- Andromeda galaxy

Figure: Andromeda Galaxy

- Distributed uniformly (homogenous and isotropic) in the universe.

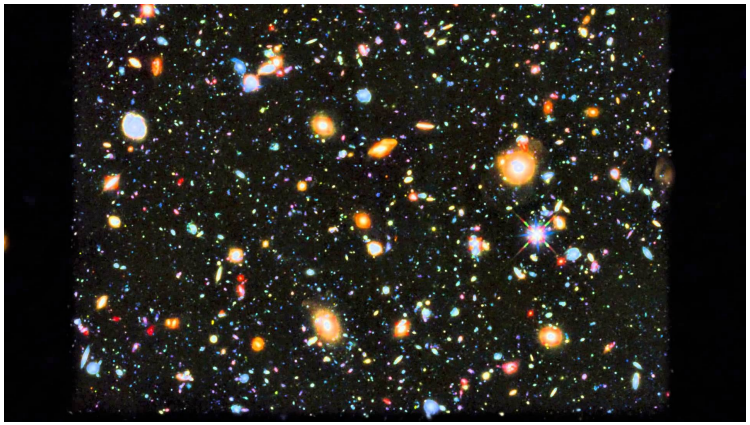


Figure: Hubble Deep field image

Static Universe - Einstein - 1917

- Only force between them is gravitation.
- Gravity may leads to contraction
- To oppose this space must have repelling force - Cosmologal constant Λ: representing this repulsion were included - to keep the universe static.
- After the discovery of the Expansion of the Universe - Cosmological constant were discarded.

Expanding Universe - Hubble's discovery

- Observe the spectra - light- form distant stars in other galaxies.
- Comparing the galaxy spectrum with lab spectrum
- Galaxy spectrum shows redshift.

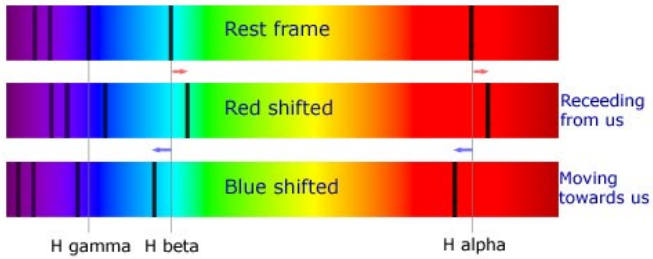
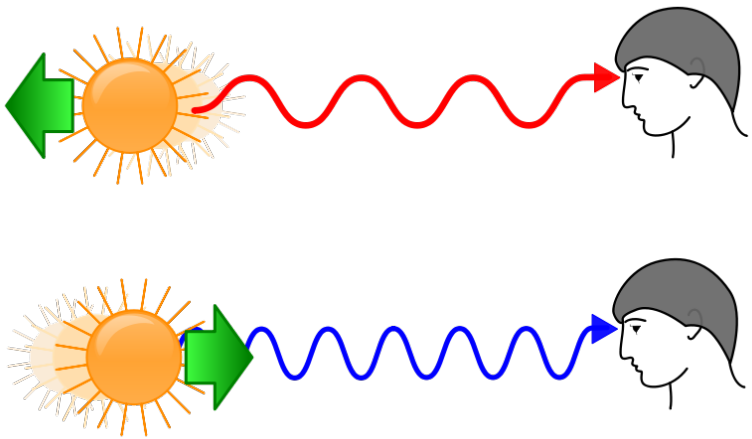


Figure: Shift in H-spectrum

- Redshift $Z = \frac{\lambda_R^{'} - \lambda_R}{\lambda_R} > 0$
- Compare with Doppler effect – galaxies are moving away from us.



- Distribution of galaxies is uniform.
- If one observe from any other galaxy also will observe the same that the galaxies are moving away from him.
- Hence galaxies are moving from each other.
- This is what we mean by the expansion of the universe!(?)

What is really expanding?

- Space is also homogeneous and isotropic (Einstein's Contribution)
- Friedmann (1922) - It is space which is expanding.
- Tha galaxies are at rest in the space.
- The expanding space is carrying the galaxies along with it.

Hubble's law

- Connsider one dimensional distribution of galaxies - remember galaxies are at rest.
- Hence coordinate position of a galaxy and coordinate seperation between galaxies are constant, Δx, say.
- But the actual distance between two galaxies at any time,

$$D = a(t)\Delta x,$$

where $a(t)$−scale factor - the factor by which the distance has been increased compared to an initial time.

- Velocity of expansion

$$V = \frac{dD(t)}{dt} = \frac{da(t)}{dt}\Delta x$$

Hubble's law

- $$V = \frac{\dot{a}(t)}{a(t)} a(t) \Delta x$$

  where $\dot{a}(t) = \frac{da(t)}{dt}$.
- that is, (Hubble's law)
$$V = HD$$
  where $H = \frac{\dot{a}t}{a(t)}$ is the Hubble parameter (constant?).(Unit is sec^{-1}
- The law says that, the velocity of expansion (velocity of galaxy) is proportional to the distance to it. The double the distance to a galaxy, the double the velocity with which it moving away.

Hubble Parameter

- Present value of the Hubble parameter $H_0 = 73 km/sec/Mpc$.
- means, if you observe a galaxy at a distance of $1Mpc$, it would be moving away with velocity of $73km/sec$.
- $1Mpc = 1MegaParsec = 10^6 Parsec$ and $pc = 3.26 lightyears$. $1lightyear = 10^{16} m$.
- Also $H_0 = 3 \times 10^{-18} sec^{-1}$.
- What is the expansion velocity at distance $1m$ away, $v(1m) = 3 \times 10^{-18} \times 1 = 3 \times 10^{-18}\, m/sec$.
- Expansion velocity at a distance 1000 LY, $v = 3 \times 10^{-18} \times 10^{19} = 30 m/sec$.
- So expansion is relevent only at intergalactic distances.
- That is only the space between galaxies are expanding.

Age of the Universe

- Let T be the age of the universe.
- But time time $t = \frac{D}{V}$.
- Hence Age $T = \frac{D}{V} = \frac{D}{HD} = \frac{1}{H}$.
- But $H = 3 \times 10^{-18} sec^{-1}$.
- Hence Age $T = \frac{1}{3 \times 10^{-18}} sec = \frac{10^{18}}{3 \times 365 \times 24 \times 60 \times} Years \sim 10^{10}$ Billion Years.
- Actual Observational Age

$$T = 13.7 Billion\ Years$$

Dynamical Evolution and History of expanding Universe

Big-Bang

- As one go back in time, the size of the unverse is decreasing and finally reached a point at which Universe was began.
- this corresponds time $t = 0$ at which the universe in infinitely dense, infinitely hot - Big-Bang
- All the known laws of Physics break down - so no idea about the origin.
- after big-bang, the evolution of described and governed by the equation - Friedmann equation

$$H^2 = \frac{8\pi G}{3}\rho(t)$$

where $\rho(t)$ is the density of matter/radiation .

Evolution after big-bang

- After big-bang, universe consists of Radiation (photons) and Matter (in the form fundamental particles, proton (p), neutron (n), electron (e) ....)
- $t = 100$seconds after big-bang , Temperature $T \sim 10^9 K$.
  1. Synthesis of light elements, $H, He, ...$ were started (by combining neutrons and protons).
  2. $t = 10,000$ years $T \sim 16000K$ - matter density begins to dominate over that of radiation (see next slide)

Evolution of matter density

- Matter density

$$\rho_m = \frac{M}{Volume} = \frac{M}{\frac{4\pi}{3}D^3} = \frac{constant}{a(t)^3}$$

- When universe is 10 times bigger, ρ_m become 1000 times less.

Evolution of Radiation density

- Energy of photon, $E = h\nu = \frac{hc}{\lambda}$
- Wave will get stretched as Universe expands, i.e. $\lambda \propto a(t)$
- Hence Energy of a photon at a time t is $E \sim \frac{hc}{a(t)}$
- Energy density of photons $\rho_r = \frac{radiation\ energy}{Volume} \propto \frac{1}{a(t)} \times \frac{1}{a(t)^3}$.

$$\rho_r \propto \frac{1}{a(t)^4}$$

- When universe 10 times bigger, ρ_r become 10,000 times less.

Radiation and Matter

- Initially Radiation density will dominate - Radiation Dominated era
- Due to the faster decrease of the radiation density, eventually the mattter density will come to dominate over density - Matter Dominated era.
- Figre Please!

Decoupling of radiation $t \sim 300,000$ years and $T \sim 3000K$

- In the beginning of the Matter Dominated phase - matter were mainly , light nuclei + electrons.
- Photons will be repeatedly scattered by electrons - Unverse is opaque to radiation.
- When T is around 3000 K, electrons will combined with nuclei and neutral atoms were fromed.
- Photons will no longer be scattered, and decoupled form matter - Universe is transparent.
- It is this radiation were become CMBR.
- The temperature of radiation were futher reduced due to the expansion.
- Present temperature is around 2.7 K.

Evolution of size with time

Radiation dominated era

- $H^2 = \frac{8\pi G}{3}\rho_r$
- $H = \frac{\dot{a}}{a}$ and $\rho_r \propto a(t)^{-4}$
- Hence size evolve as $a(t) \sim t^{1/2}$

Matter dominated era

- $\rho_m \propto a(t)^{-3}$
- size evolve as $a(t) \sim t^{2/3}$

figure please!

Dark Energy and Late acceleration

- Observation shows that, the present universe is accelerating in expansion (1998).
- there exist some exotic form of enery called dark energy which antigravitating in nature.
- It's density is almost a constant throughout the evolution, $\rho_\Lambda = Constant$.
- It dominates the matter density some 5 billion yeras back.
- What exactly dark energy composed of ???????????

Present Estimates of Radiation, Matter, Dark energy

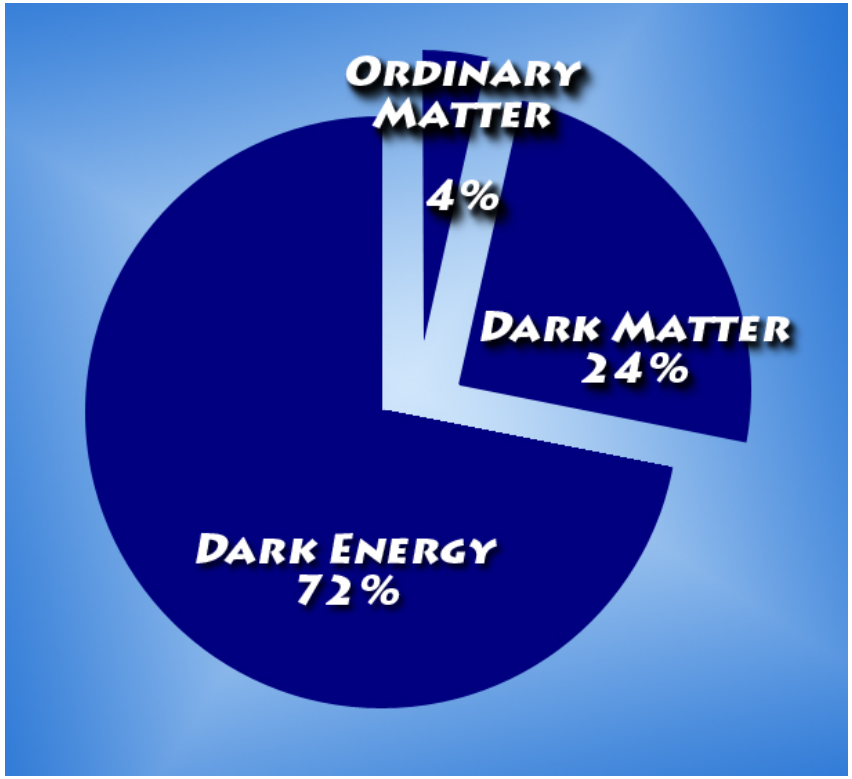


Figure: Proporton different components of the universe