Vaishnav Rao

Cosmology
Pre-class reading 2

Dependence of the age of the Universe on cosmological parameters:

Age of the universe: Time since the Big Bang. If we are comparing multiple universes with different cosmological parameters, this time would be the time elapsed since the Big Bang for the Universe to reach the currently observed expansion rate.

- Hubble's Constant: Age of the universe ~1/H0 (Hubble time). Thus, larger H0 will result in younger ages.
- Matter fraction: Matter, due to gravity, counteracts expansion. For a Universe with a larger matter content, after the Big Bang, the deceleration of the Universe is larger. This means that it takes the Universe less time to decelerate to the currently observed expansion rates, making it younger. Thus, more matter content leads to a younger Universe and vice-versa
- Dark Energy: This causes acceleration and drives expansion. So the effect is opposite. A Universe with higher fraction of DE, has slower deceleration to current expansion rates after the Big Bang, making it older.

Distances in cosmology:

- Comoving coordinate distance: Represents distances that remain fixed for objects moving with the Hubble flow. Does not depend on cosmological parameters and remains constant with time
- Proper distance: The frame-invariant, actual distance between two points that changes with time as the universe expands. Proper distance = scale factor (as a function of time) x comoving distance. This depends on the cosmological parameters through the scale factor
- Angular diameter distance: Relates an objects physical size to its actual size.
- Luminosity distance: Defined by comparing observed flux with intrinsic luminosity (f = L/4pi d^2)

Composition of matter at different cosmological epochs:

- At 10^13 K, quarks were not bound into hadrons. Universe was in a quark soup composed of quarks, leptons, and protons
- T~3e12 K/ t ~1e-5 s: Quark-hadron phase transition confining quarks into baryons and mesons. Universe is mainly 3 types of relativistic pions, non-relativistic nucleons, charged leptons, and associated neutrinos
- T~1e12 K/ t~1e-4 s: Pairs annihilate and neutral pion decays to photon. Muons annihilate and become negligibly small
- T~5e9 K/ t~4 s: Electron-positron annihilation. n/p ratio freezes out at ~1/10
- T~1e9 K/ t~ few minutes: Nucleosynthesis starts- production of D, He, and a few other elements. Plasma of electrons and ions. Freely expanding neutrinos. Start of neutral atom formation
- T~ 4000K/ t~2e5 yr: Recombination. 50% of baryonic matter neutral. Transparent to photons- origin of CMB radiation. Matter dominated epoch begins

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Pre-class reading 2:

1) $R_0 = 1\text{Mpc}$ at $z=0$ (comoving distance)

$\rightarrow$ $R_0 = 1\text{Mpc}$ at $z=1$

Proper distance $l = a(t)\, R_0$

$l_0 = a(t_0)\, R_0 = R_0$ t_0 is at $z=0$ & $l_0 = R_0$ at t_0

$$1+z = \frac{a(t_0)}{a(t)}$$

$\therefore$ $z=1$ $a(t) = 1/2$

$\therefore$ $l_{z=1} = 0.5\,\text{Mpc}$ (Proper distance at $z=1$)

2) $z=1$ $d_A = 1675.3\,\text{Mpc}$ $d_L = 6701\,\text{Mpc}$

$z=10$ $d_A = 877.6\,\text{Mpc}$ $d_L = 106{,}188\,\text{Mpc}$

} Ned Wright's Cosmo calculator

Does not agree with immediate intuition

JWST can better resolve spatial structures at $z=10$

3) $f = 1/4\pi d_L^2$ $z=10$ galaxy will be fainter by a factor of 251

4) $$t_0 = \frac{2}{3} H_0^{-1} \frac{1}{\sqrt{\Omega_\Lambda}} \sinh^{-1}\left(\sqrt{\frac{\Omega_\Lambda}{\Omega_m}}\right)$$ (wikipedia)

with DE : $\Omega_m \sim 0.3$ $t_0 \sim 13.8$ Gyr

$\Omega_\Lambda \sim 0.7$

without DE: $\Omega_\Lambda = 0$ $t_0 \sim 9\text{-}10$ Gyr

Oldest GC ages : 12-13 Gyr

Consistent with this