Wednesday, October 14, 2015 1:22 PM

At earlier times, $a \propto t^{1/2}$, so temp. evolves as $\frac{T}{T_{rm}} = \left(\frac{t_{rm}}{t}\right)^{1/2}$

Or, more preciesly,

neutrinos

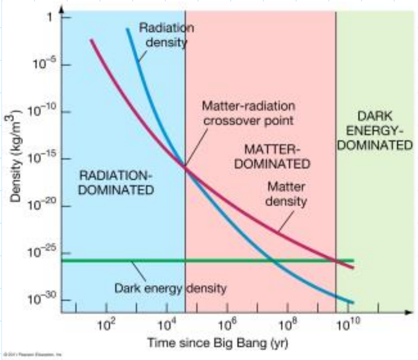
rad'n constant

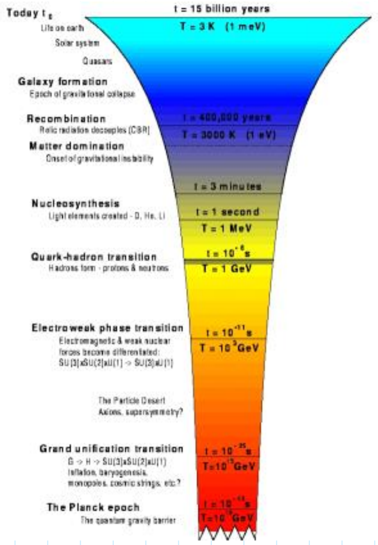
$$H^2 = \frac{8\pi G\rho}{3} = \frac{8\pi G}{3}\cdot(1.68)\frac{aT^4}{c^2}$$

in rad'n dom. environment, $H = \frac{1}{2t}$ so

$$\left(\frac{1\,\text{sec}}{t}\right)^{1/2} \simeq \left(\frac{T}{1.3\times10^{10}\,K}\right) = \frac{kT}{1.1\,\text{MeV}}$$

At $t \sim 1s$, the typical photon energies are approx. nuclear binding energies. Prior to 1s, nuclei would be destroyed.





Nucleosynthesis

One of the striking pieces of evidence of the Hot Big Bang Model is the prediction of the abundance of light elements (He, D, Li). Indeed, the He^4 abundance is observed to never fall below ~23% by mass. Need $5\times10^8 K < T < 5\times10^{10} K$ for fusion of light elements, so this is all possible $\gtrsim 1s$ after the B.B.

Lets focus on production of He^4

1) protons are slightly lighter than neutrons (by 1.3 MeV)

2) free nuetrons have a half-life of 614s

3) bound neutrons do not decay

When the T is large enough to destroy any nuclei reactions like

$$p + e^- \longleftrightarrow n + \nu_e$$
$$n + e^+ \longleftrightarrow p + \bar{\nu}_e$$
$$n \longleftrightarrow p + e^- + \bar{\nu}_e$$

are in equilibrium (happen faster than the exp. of the Univ.)

$$\frac{n(n)}{} = e^{-\Delta mc^2/kT}\left(\frac{m_n}{}\right)^{3/2}$$

$$\frac{n(n)}{n(p)} = e^{-\Delta mc^2/KT}\left(\frac{m_n}{m_p}\right)^{3/2}$$

Will hold as long as $KT > 0.8\,\text{MeV}$, then the rel. abundances of n & p will be fixed except for n decay $\frac{n(n)}{n(p)} \simeq e^{-1.3/0.8} \simeq \frac{1}{5}$

Afterwards, get

$$p+n \rightarrow D+\gamma$$
$$D+D \rightarrow He^3+\gamma$$
$$\searrow H^3+p$$
$$He^3+n \rightarrow He^4+\gamma$$
$$H^3+D \rightarrow He^4+n$$
$$H^3+p \rightarrow He^4+\gamma\text{, etc.}$$

The destructive reactions stop being important when $KT \simeq 0.06\,\text{MeV}$ $(t \simeq 340\,\text{s})$

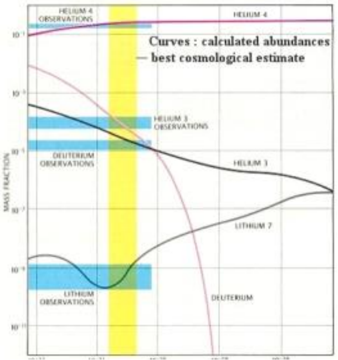
$\therefore$ $n(n)$ is reduced by $e^{-(\ln 2 \times 340/614)}$

so $\frac{n(n)}{n(p)} \simeq \frac{1}{7.3} \simeq 0.136$

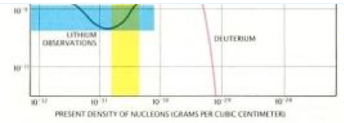
If all the n are used in He^4 then fraction of the total mass in He^4 is

$$Y_4 = \frac{2n_n}{n_n+n_p} = \frac{2}{1+\frac{n_p}{n_n}} \simeq 0.24$$

A more careful treatment of nuclear physics gives estimate of He^3, D, Li. Big Bang is the only Known source of D. Predictions depend only on the # of ν species (best fit 3) & the density of baryons ρ_B.



Agreement w/ observations occurs over a small range of ρ_B, $\Omega_B h^2 \simeq 0.02$. Since $\Omega_{m,0} \simeq 0.2\text{-}0.3$ the dark matter is non-baryonic



Whole process takes only a couple of minutes once photons 'decouple' from nuclei.

Where are the anti-baryons?

Unknown. Need some small (1 part in a 10^9) asymmetry in baryon/anti-baryon production.

New particle physics?