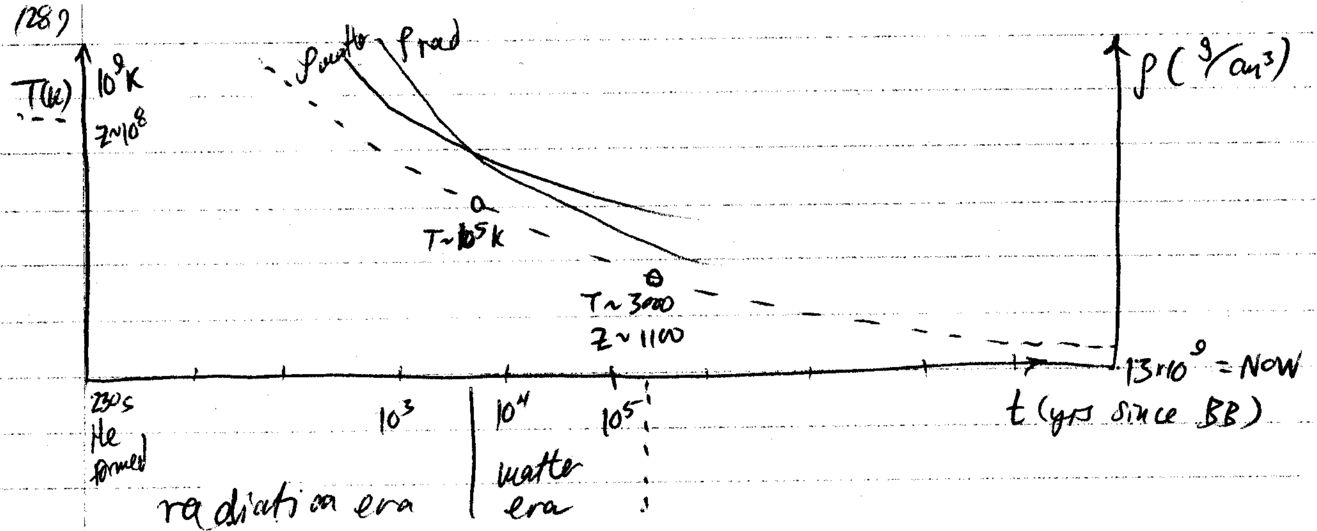
PS Spring - week 8

19 May 03 - E/Z

Ch 28 - THE EARLY UNIVERSE

§28.1 (1289) CONSTRUCTING THE UNIVERSE



$T \propto t^{-1/2}$
$R \propto t^{1/2}$

"recombination" of neutral atoms → decoupLING of matter + rad
300,000 yrs

B²FH: **BIG BANG NUCLEOSYNTHESIS in RADIATION ERA** (before $10^{\prime\prime}$s)

He abundance due to fusion in first 3 minutes (not much from stars)

At $T \sim 10^{12}$ K, $\frac{n_n}{n_p} = 0.985$ (Boltzmann $\frac{28.4}{1290}$)

Around $T \sim 10^{10}$ K, $E_\gamma < 2m_e$ ∴ $e^- + e^+$ annihilate, leaving (plus ν_e drops) too few e^- to drive $p + e^- + \bar{\nu}_e \to n$

$$\frac{n_n}{n_p} = \frac{223}{1000} \xrightarrow[n \to p+e+\bar{\nu}]{} \frac{172}{1051}$$

10^{10} K $\qquad$ 10^9 K

p.1291 Below 10^9 K, He nuclei form = MOST TIGHTLY BOUND light nucleus

p.1292 $(172\,n) + (1051\,p) \to \left(\frac{172}{2} = \underline{86\ {}^4_2He}\right) + (1051 - 172 = \underline{879\,p}) + 0\,n$

$$\frac{m_{He}}{m_{tot}} = \frac{4 \cdot N_{He}}{N_p + 4 \cdot N_{He}} = \frac{4 \cdot 86}{879 + 4(86)} = 0.28$$

(PRE)

GALAXY + CLUSTER Structures form in MATTER ERA

p.1293 **ADIABATIC** fluctuations

$\Delta = \frac{\delta\rho}{\rho}$ same for RAD + MATTER

p.1295 $\Delta \propto t$ (RAD era), $\Delta \propto t^{2/3}$ (Matter Era)

p.1296 JEAN'S MASS = M_{min} for self-grav.

Before decoupling: $v_s \sim \frac{c}{\sqrt{3}}$!

$$M_J \propto \frac{\rho_{baryons}\, v_s^3}{\rho_{photons}^{3/2}} \propto \frac{T^3}{(T^4)^{3/2}} \propto \frac{1}{T^3}$$

until recombination: $M_J \propto T^{3/2} \propto v_s^3$

p.1297 RAD era: Δ = const

MATTER era: ACOUSTIC OSCILLATIONS!

p.1298 smooth out small Δ < photon distance

surviving Δ have $M_{min} \sim 10^{13} M_\odot$

SIZE of small GAL. CLUSTERS

ISOTHERMAL fluctuations

$\Delta = \frac{\delta\rho}{\rho} = 0$ for everything (constant density)

preserves Δ from dissipation of acoustic osc.
no changes until recombination

Δ can grow

After recombination:
$M_J \sim 10^6 M_\odot$ (p.1299)

SIZE OF Globular CLUSTER (stellar)

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p.1299 Ex 1: Observed radio-quiet quasars at $z \sim 5$ require $\Delta \sim 10^{-3}$ at recombination (decoupling)

p.1300 HOWEVER, anisotropies in CBR imply $\Delta_{recom} \sim 10^{-5}$

BARYONIC matter cannot clump fast enough to make observed structures
$\therefore$ 99% is DARK MATTER

SURPRISE: LOWER Δ CBR regions: COOLER (gas) < HOTTER (grav redshift)!

p. 1302 DARK MATTER ≈ 94% ($\rho_{\text{baryonic}} < 6\% \, \rho_{\text{univ}}$)

HOT DARK MATTER

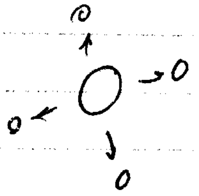
neutrinos : $m \sim 7 - 25$ eV

$N_\nu \sim 10^{90}$ = # of primordial photons

Ex: calculate Σm_ν = ______

$\frac{\rho_\nu}{\rho_c}$ = ______

Like ADIABATIC Δ,
ν resist clumping ∴
TOP DOWN formation



p. 1318 However, breakup into galaxies may occur too late

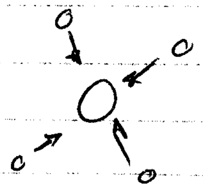
COLD DARK MATTER

WIMPS : $m \sim 10^{10-12}$ eV

AXIONS : $m \sim 10^{-5}$ eV

NEITHER HAS BEEN OBSERVED

COLD DM clumps more readily ∴
BOTTOM-UP formation



perhaps a better fit to observations

However, hard to account for voids

1319 SYMMETRY BREAKING → COSMIC DISCONTINUITIES?

0D: monopole; 10^{16} GeV
14 Feb 82?

1D: cosmic string 10^{21} g/cm
false vacuum moving at $v \sim c$?

2D: domain wall

3D texture

INFLATION: See Ch 21 universe lecture

28.13 In Problem 9.3, you derived Eq. (9.60) for the number density of blackbody photons,

$$n = \frac{u}{2.70kT} = \frac{aT^3}{2.70k}. \approx \frac{\text{photons}}{\text{volume}}$$

Use this result along with the baryon density, $\rho_{B,0}$, to estimate the ratio of the number of baryons to the number of photons in today's universe. For convenience, assume that the universe is made solely of hydrogen.

use $T = 2.73\ K$

28.14 Estimate the thickness of a typical cosmic string.

From Prob #9.3 :

$\frac{(9.5)}{256}$ $u = \frac{4\sigma T^4}{c} = aT^4$

$\frac{(9.60)}{307}$ $\frac{u}{n} = \frac{\pi^4 kT}{15(2.404)} = 2.70\ kT$

$n_{photons} =$

present $n_{baryons} = n_{B,0} = \frac{\rho_{B,0}}{m_H}$ ← (27.16) p. 1228
← assume Hydrogen universe

$n_{B0} =$

$\frac{n_{B,0}}{n_{photons}} =$

28.14 Cosmic strings have $\frac{\text{density}}{\text{length}} \approx \lambda \sim 10^{21}\ g/cm = \frac{\text{mass}}{\text{vol.}\ \text{length}}$

False vacuum has energy density $= \frac{\text{energy}}{\text{vol}} \approx 10^{95}\ \frac{\text{erg}}{\text{cm}^3}$ $\frac{(28.13)}{1312}$

$\frac{\text{Energy}}{\text{length}} = \frac{mc^2}{\text{length}} =$

Assume Area $= \pi r^2$ and solve for r :