More homework: CO probs. 29.20, 29.21 (= 27.18, 27.20 in 1st ed.)
Due Wed. Oct. 24, along with CO 29.9 (= 27.11 in 1st ed) and 29.12

Primordial Nucleosynthesis

Radiation era: $R(t) \propto t^{1/2}$; RT = constant = 2.726 °K $\Rightarrow T(t) \propto t^{-1/2}$

$t = 10^{-4}$ s, $T = 10^{12}$ K

$p^+ + e^- \rightleftarrows n + \nu_e$, etc. electrons from $\gamma \rightleftarrows e^- + e^+$

Statistical equilibrium $\frac{n_n}{n_p} = e^{-\frac{\Delta E}{kT}} = e^{-\frac{1.5\times10^{10}\,K}{T}}$

$t \sim 1$ s, $T \sim 1\times10^{10}$ K

neutrons "freeze out"
- redshifting of neutrinos
- lower γ energies.

$\frac{n_n}{n_p} = 0.223$

subsequent β decays $\Rightarrow$ $\frac{n_n}{n_p} \sim 0.176$

Revised value from CO 2nd ed.

$t \sim 3$ min, $T \sim 10^9$ K

^{4}He production:

$d + d \rightleftarrows {}^3\mathrm{He} + {}^1\mathrm{H}$

${}^3\mathrm{He} + d \rightleftarrows {}^4\mathrm{He} + n$

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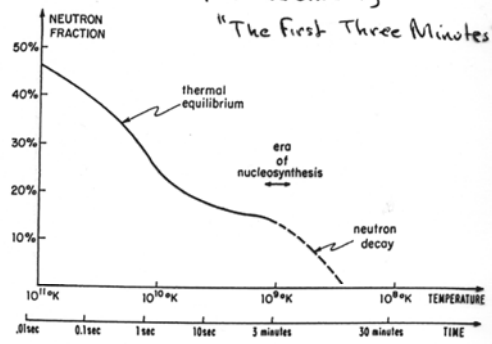
~all neutrons $\longrightarrow$ ^{4}He

$\Rightarrow$ mass fraction of ^{4}He

$= \frac{2n_n}{n_n + n_p} \sim 0.299$

from Weinberg "The First Three Minutes"

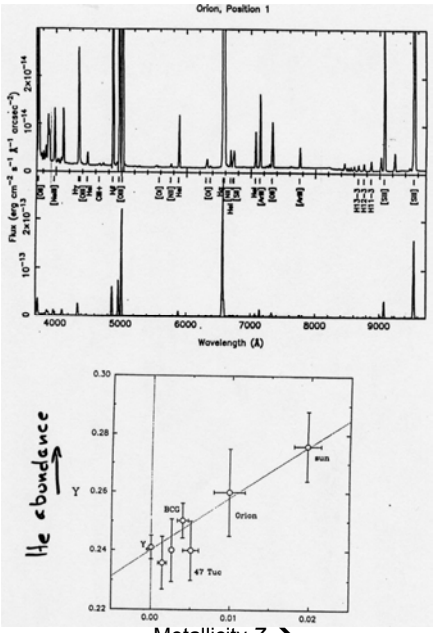


Roughly independent of exact density

Observed $\frac{^4\mathrm{He}}{\mathrm{Total}} = 0.228 \pm .005$ (Pagel et al. 1992)

or something close to that.

Measuring Primordial Helium



Additional ^{4}He is produced in stars, so must extrapolate back to metals (Z) = 0.

Measuring Baryonic Matter Density – Version I

- ^{4}He ➔ very few constraints on cosmology
- But trace elements produced at same time:

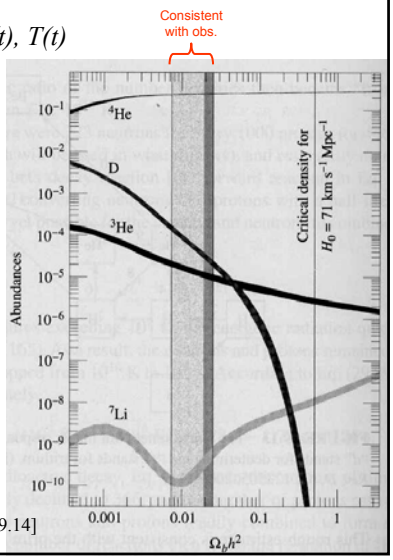
  amounts depend strongly on $\rho_{BARYON}(t)$, $T(t)$

  ➔ $\rho_{B,o}$ from RT = constant,

  $\rho = \rho_o/R^3 \propto \rho_o T^3$

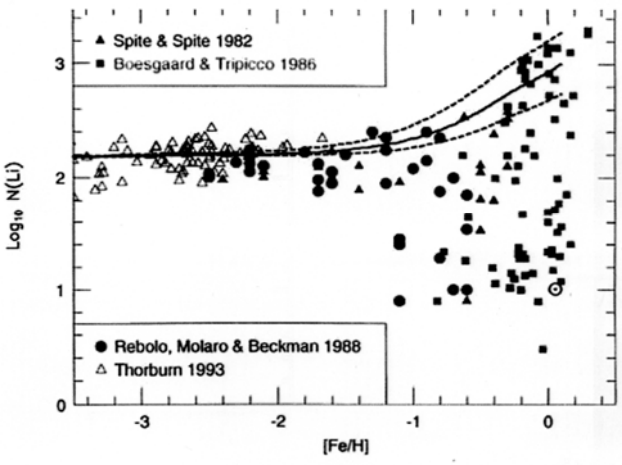
Baryons:
Particles made of 3 quarks
= protons, neutrons, + …
= "normal matter"

A Problem: d, ^{3}He, ^{7}Li are all easily destroyed in stars. How to measure primordial values?



[CO Fig 29.14]

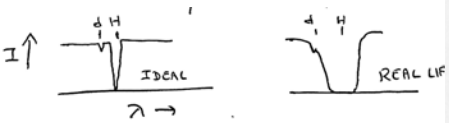
Primordial Lithium Abundance

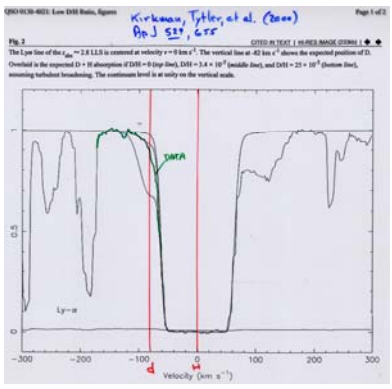


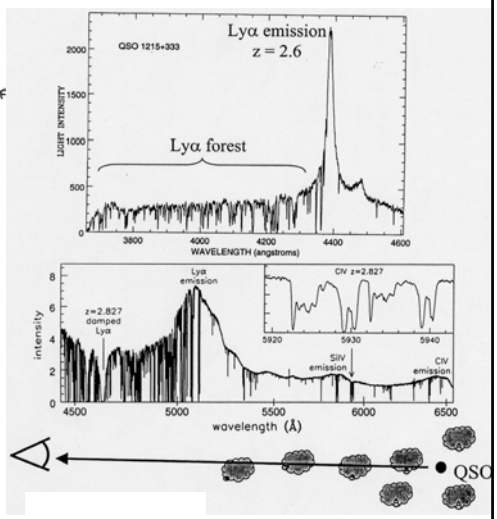
The "Spite Lithium Plateau"

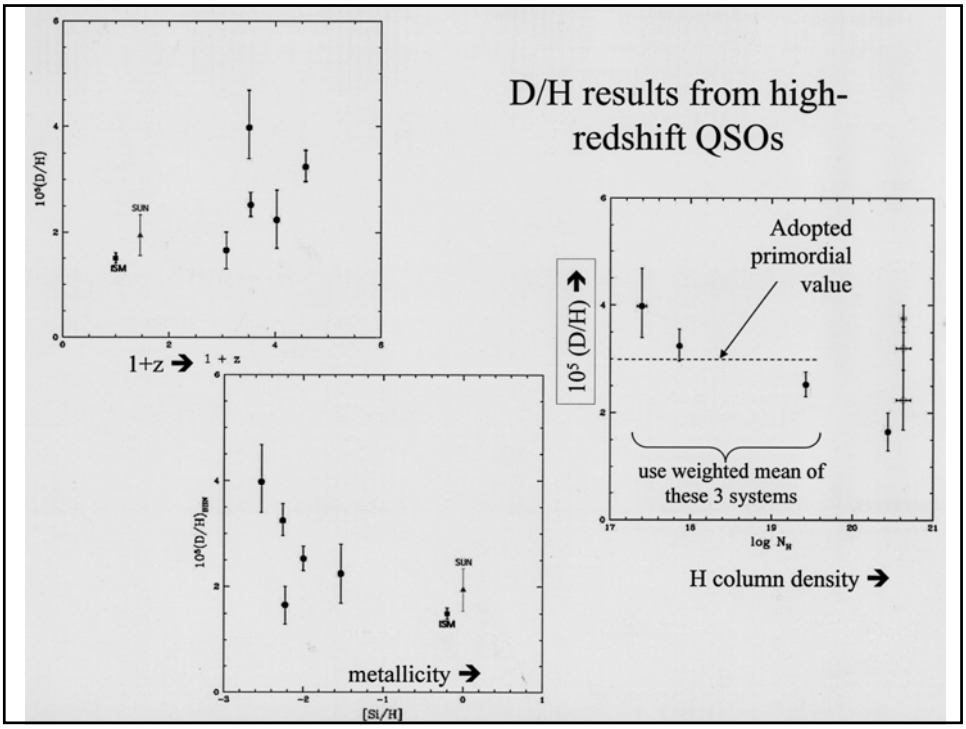
Measuring the Primordial Deuterium Abundance

Lyα forest absorbers.









$\Omega_{Baryons}$

- D, ^{7}Li, ^{3}He ➔ $\rho_{B,o} \sim 2\text{-}5 \times 10^{-31}$ g cm^{-3}
- Critical density = $1.88 \times 10^{-29}\, h^2 = 9.5 \times 10^{-30}$ g cm^{-3} for $h = 0.71$

$$\Omega_B = \frac{\rho_{B,o}}{\rho_{c,o}} = 0.02 - 0.05$$

- Luminous baryonic matter:

$$\Omega_{LUM} \sim 0.005$$

(x-ray emission from hot gas filling galaxy clusters).

➔ most baryonic matter is in Lyα forest clouds.

- But better determination now from CMB fluctuations (WMAP)

$$\Omega_B = 0.044$$