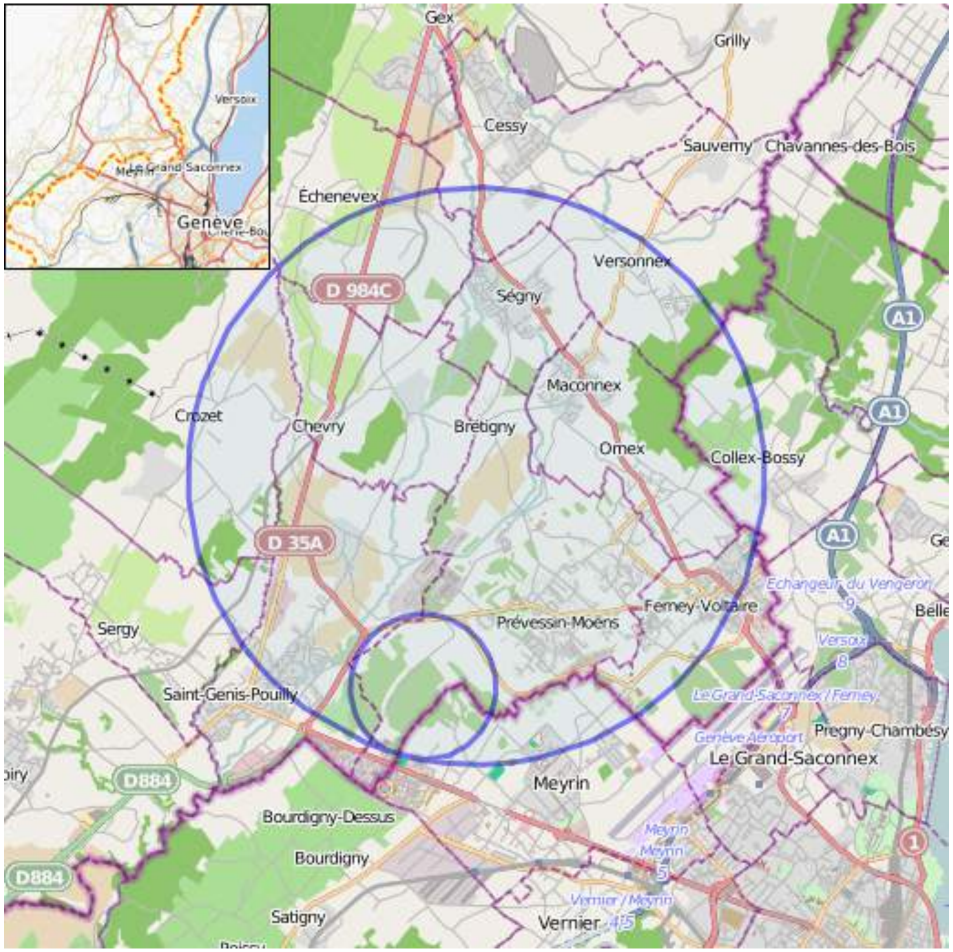
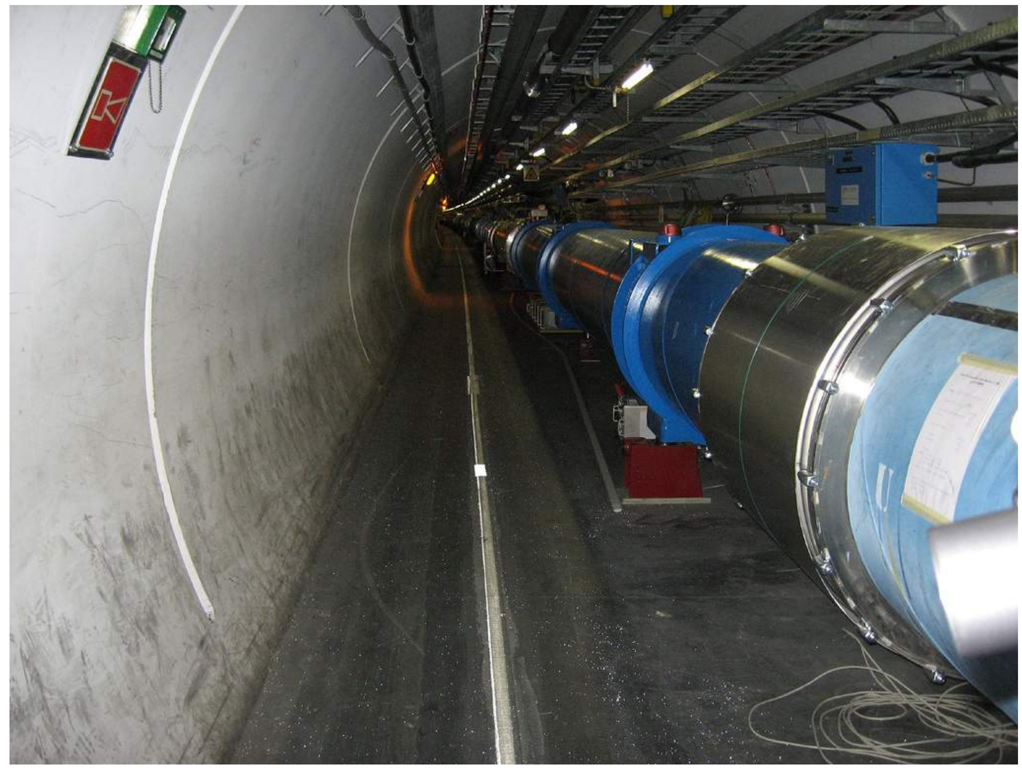
# Big Bang nucleosynthesis

# The early universe vs. the Large Hadron Collider

LHC is 27 km in circumference




Accelerates protons to ~13 TeV



$$\text{Universe: } t \approx 10^{-13}\ \mathrm{s} \left(\frac{E_{\mathrm{mean}}}{10\ \mathrm{TeV}}\right)^{-2}$$

LHC Wikipedia

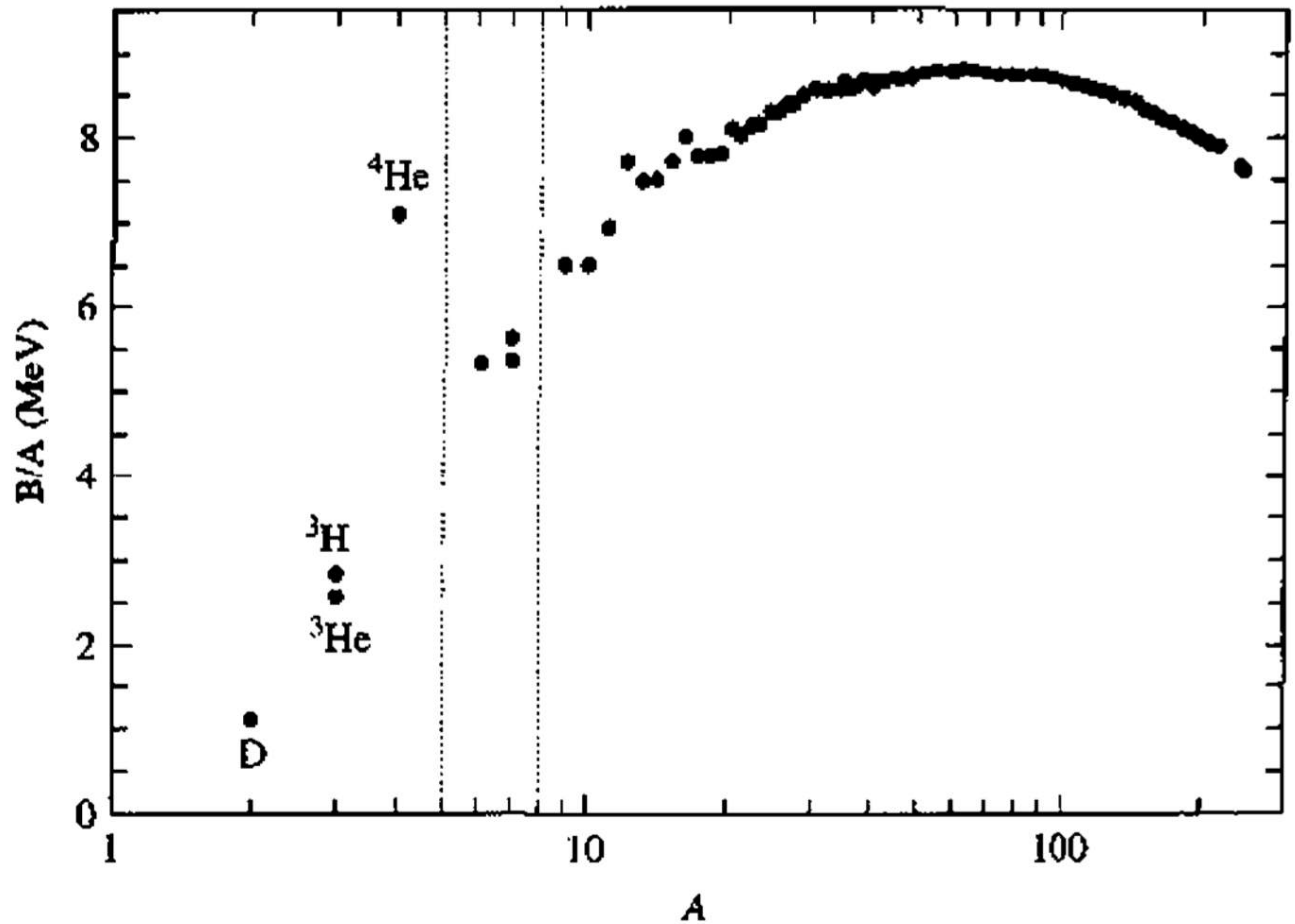



**FIGURE 10.1** The binding energy per nucleon (B/A) as a function of the number of nucleons (protons and neutrons) in an atomic nucleus. Note the absence of nuclei at $A = 5$ and $A = 8$.

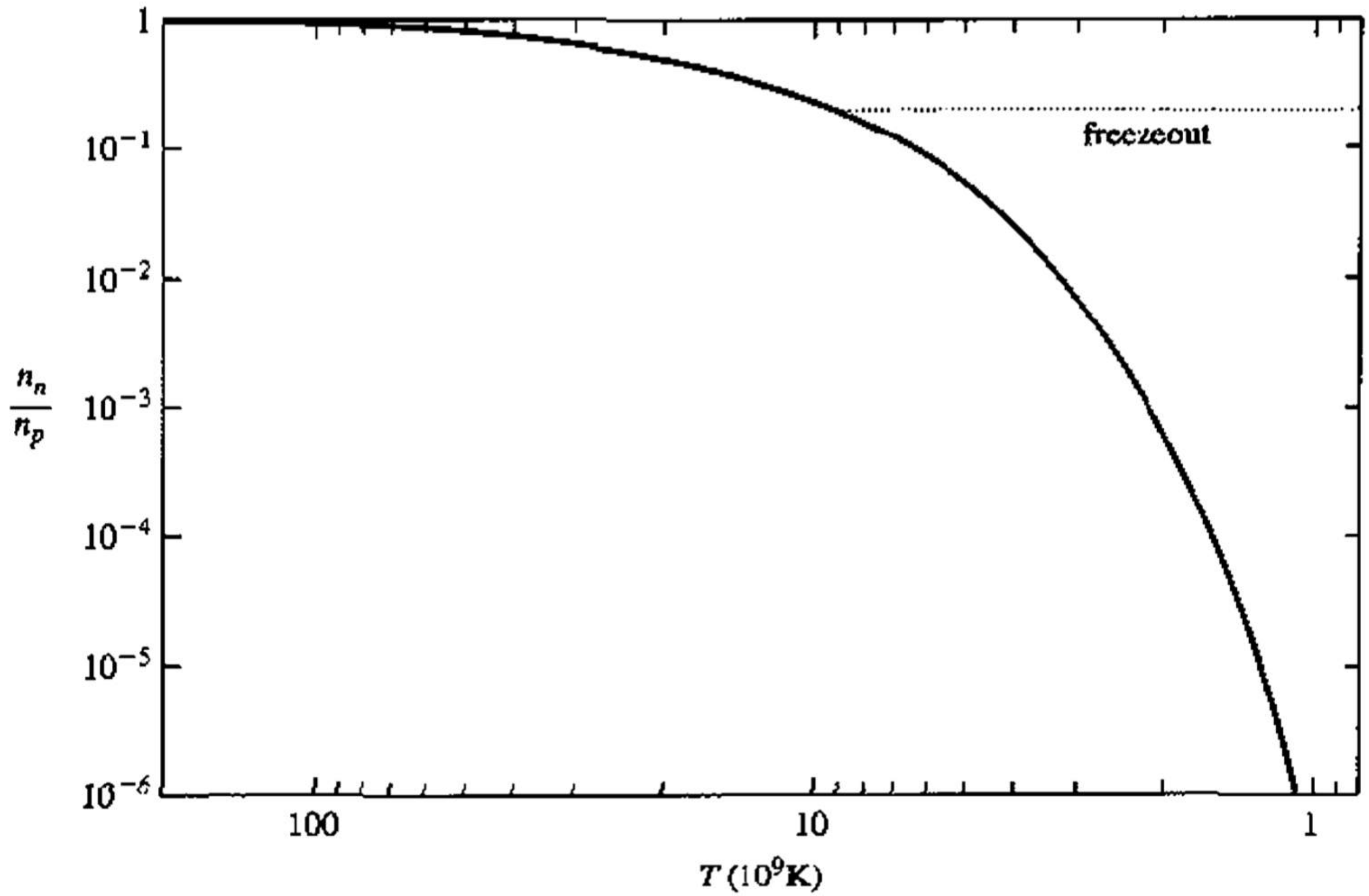



**FIGURE 10.2** Neutron-to-proton ratio in the early universe. The solid line assumes equilibrium; the dotted line gives the value after freezeout.

Ryden

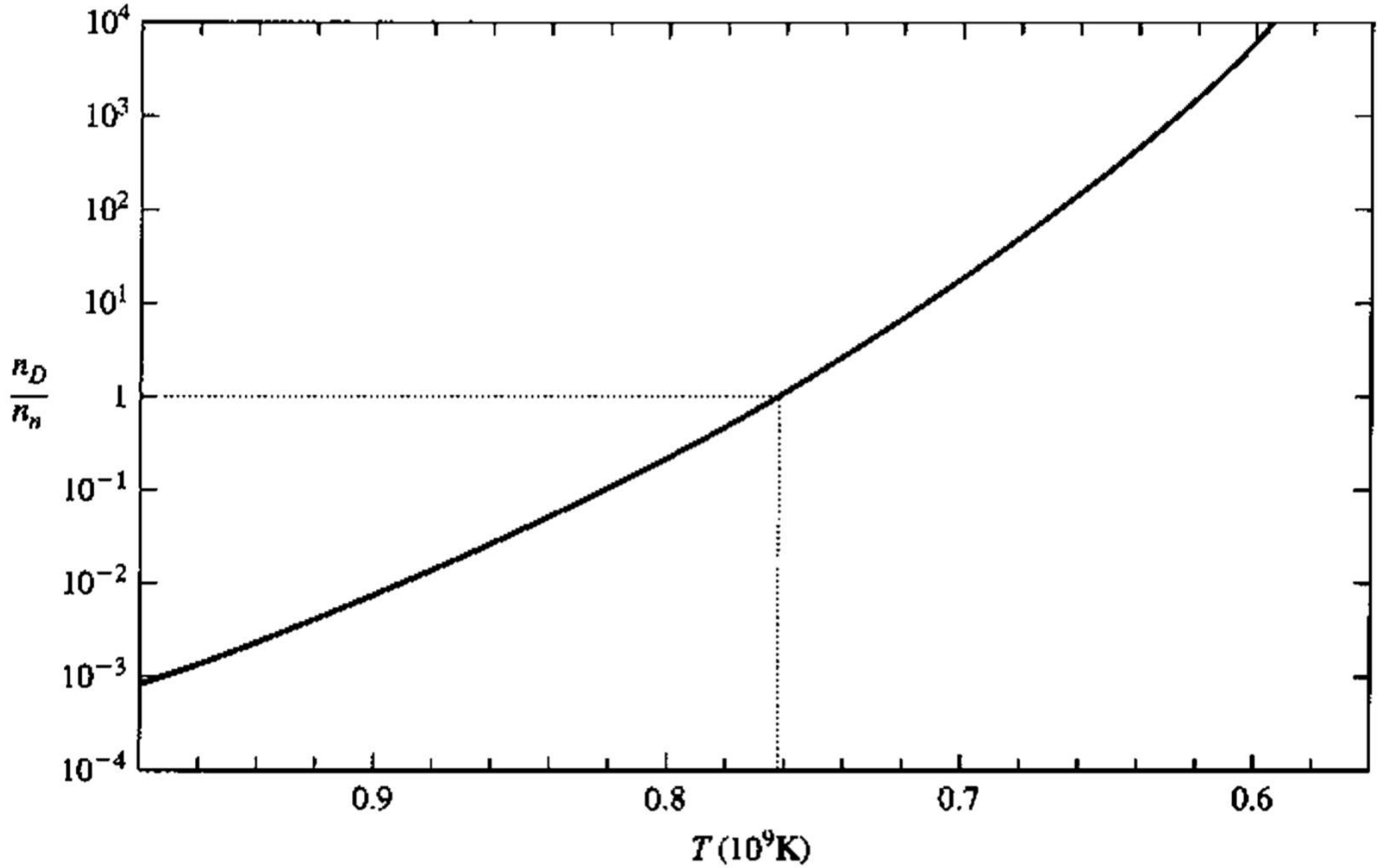



**FIGURE 10.3** The deuterium-to-neutron ratio during the epoch of deuterium synthesis. The nucleosynthetic equivalent of the Saha equation (equation (10.27)) is assumed to hold true.

Ryden

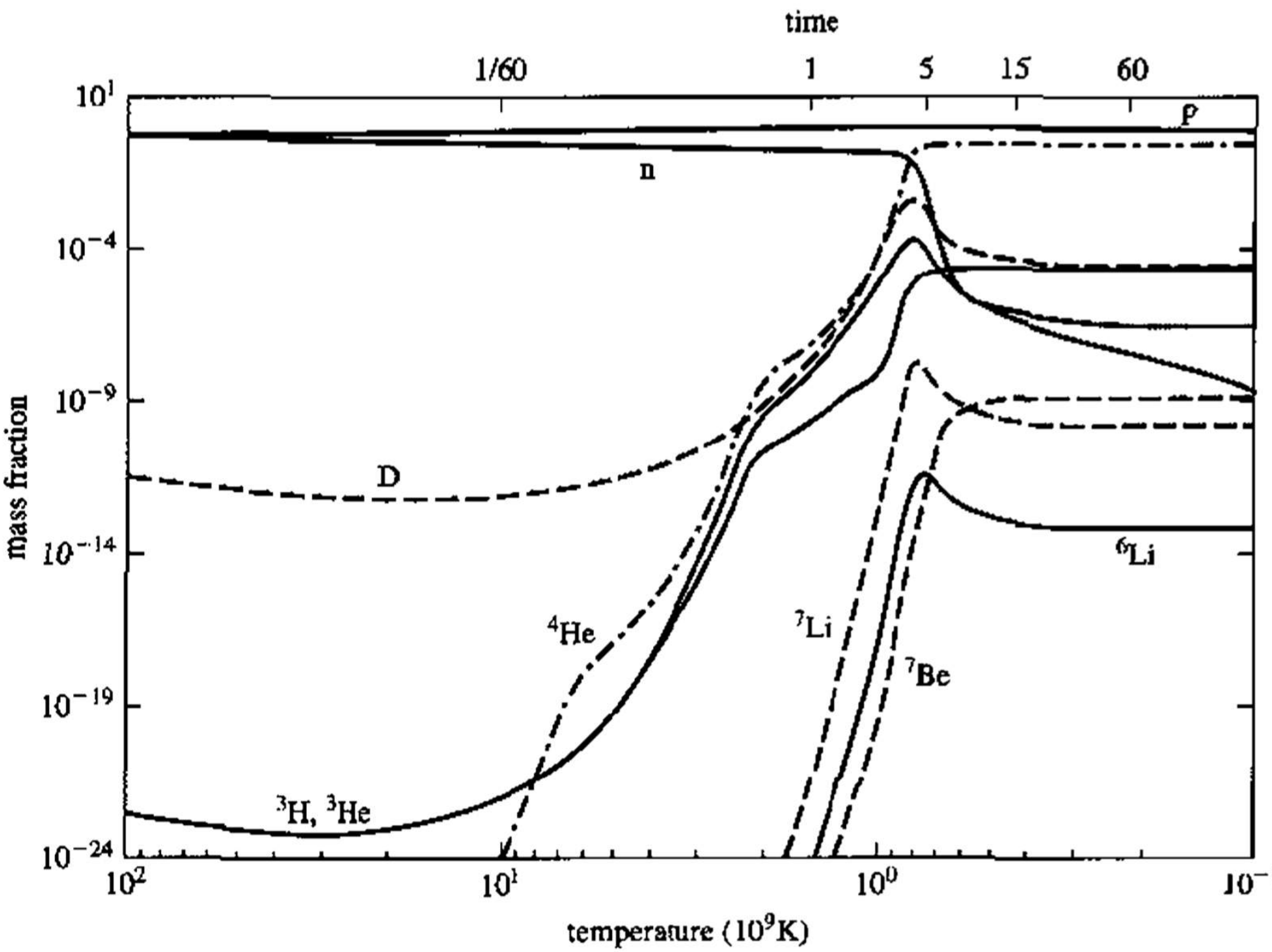



**FIGURE 10.4** Mass fraction of nuclei as a function of time during the epoch of nucleosynthesis. A baryon-to-photon ratio of $\eta = 5.1 \times 10^{-10}$ is assumed.

Ryden

# Baryon density from BBN vs. CMB

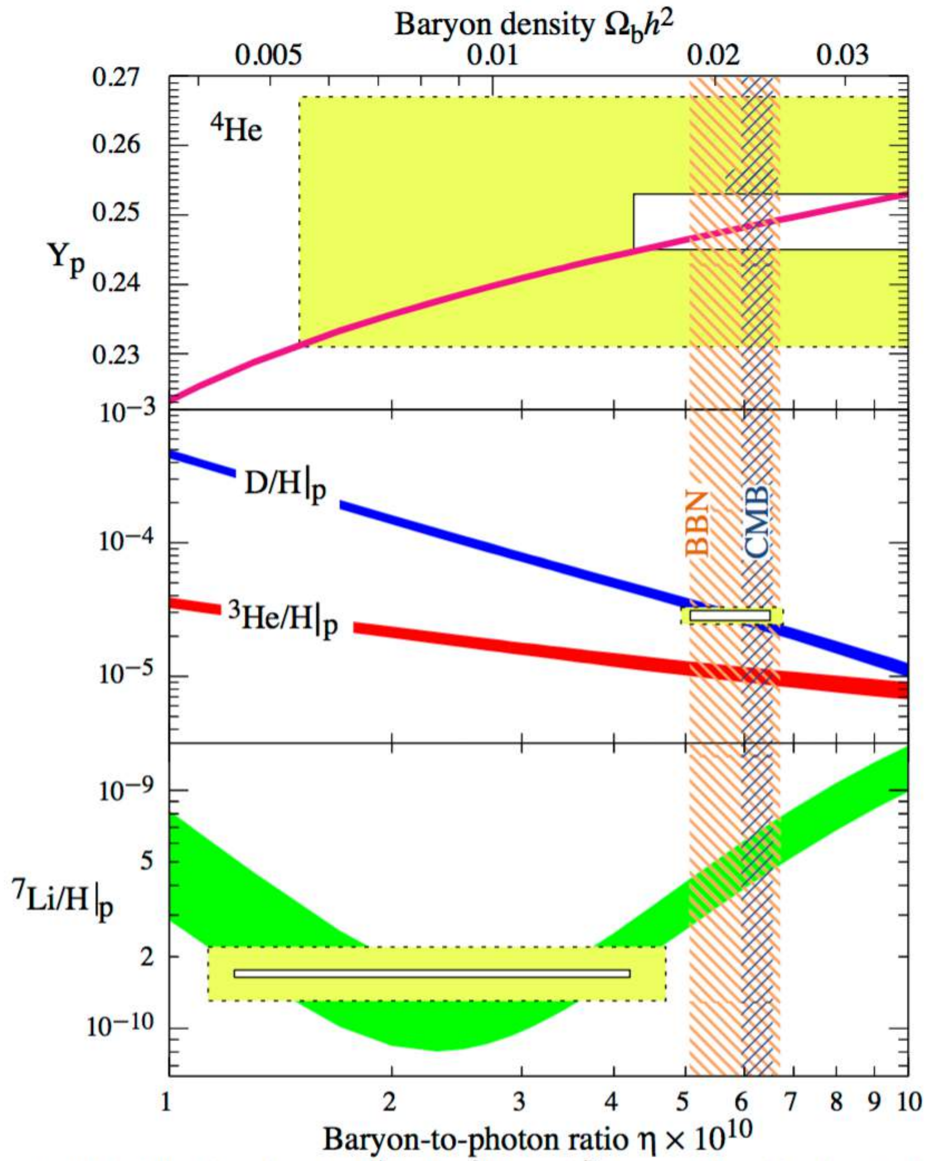



**Figure 20.1:** The abundances of $^4$He, D, $^3$He, and $^7$Li as predicted by the standard model of Big-Bang nucleosynthesis [14] – the bands show the 95% CL range. Boxes indicate the observed light element abundances (smaller boxes: $\pm 2\sigma$ statistical errors; larger boxes: $\pm 2\sigma$ statistical *and* systematic errors). The narrow vertical band indicates the CMB measure of the cosmic baryon density, while the wider band indicates the BBN concordance range (both at 95% CL).

Particle Data Group