BBN in Early Universe

t	T	Event
10^{-3} s	10^{12} K	proton–antiproton annihilation only ~ 1 proton left for every ~2 billion proton–antiproton pairs
1 s		neutrinos decouple; neutrons freeze out neutrons start to decay $\tau_{1/2} \approx 611$ s
10^{2} s	10^{10} K	BBN — extra energy from fusion dumped into radiation field, which forever remains a little hotter than the neutrino background.

Neutrons are still around at time of BBN
but are decaying, so less numerous than protons

To first order, there is 1 neutron for every 7 protons

Almost all available neutrons combine into α particles (He^4 nuclei)
So the net result is

$$12\ {}^1H \text{ for every } 1\ {}^4He$$

or in terms of mass fraction, $X_p \approx \frac{3}{4}$ & $Y_p \approx \frac{1}{4}$

Along the way, also make traces of ${}^2H$, ${}^3H$, ${}^3He$, ${}^6Li$, ${}^7Li$, ${}^7Be$

Deuterium (${}^2H$) gets made first, then gets made into heavier things

Getting protons to combine into ${}^2H$ is hard:
causes a bottleneck that slows production of heavier nuclei

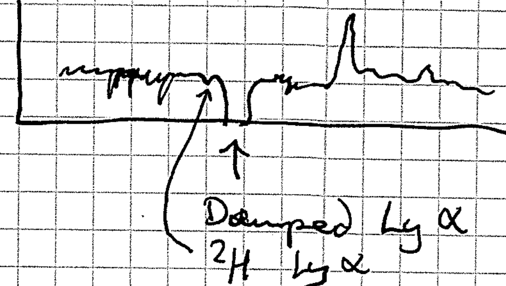
${}^4He$ is a very stable, closed-shell nucleus; plus there is no stable $A=5$ nucleus, so this is a near-terminal bottleneck.

${}^7Be$ decays to ${}^7Li$, so that's the heaviest isotope to emerge from BBN

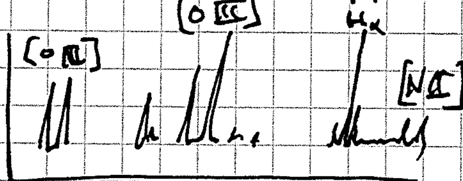
(no stable $A=8$)

BBN Observations

Deuterium $^2H/H$ ratio observed in the damped Lyman α absorption towards some QSOs



Helium $^4He/H$ observed in low metallicity HII regions of nearby dwarf galaxies



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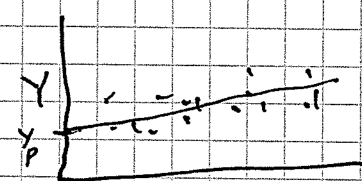

Lithium $^7Li/H$ measured in the spectra of ancient metal poor stars.

Persistently gives lower Ω_b than ^2H.

^3He hard to isolate primordial sample. Jupiter?

^6Li too abundant; has perhaps been enhanced by spallation or geological processes