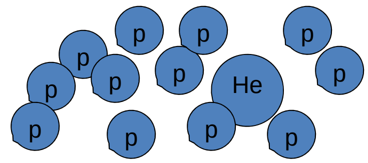
Helium Production in Big Bang—10 Nov

- Homework 8 is on angel. Due noon on Mon, 15 Nov.
- Homework 9 will be due Fri, 19 Nov at start of class. No late papers. Covered on Test 3 (22 Nov).
  - Long assignment. Start early.
- A fossil is a remnant or trace of the past. What is a fossil from the Big Bang?
  - There are 7 protons for every neutron
  - The surface of the sun is 25% He and 75% H.
- What does that fossil tell about the BB?



Fossil from Big Bang

Fossil from Burgess Shale

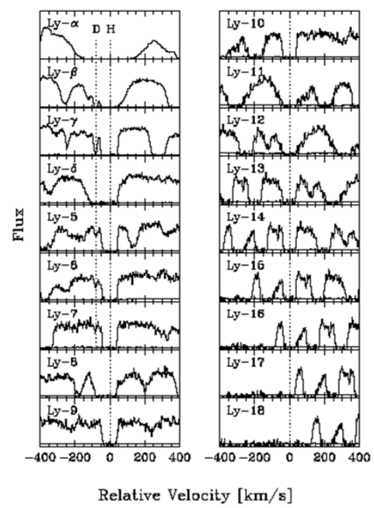
Objectives

- What are the fossils (something that can be examined) from the universe at 3 min?
- What did astronomers learn by examining the fossils?

"Collecting the Fossil"

- ^{4}He, ^{7}Li, ^{2}H, & ^{3}He are made in BB.
  - Lots of ^{4}He
  - Trace amounts of ^{7}Li, ^{2}H, & ^{3}He. Diagnostics.
- Measure abundances with spectra of "primordial objects"
  - First stars in our galaxy, made before much of the material had been processed through stars.
  - Dwarf galaxies, where material is processed through stars very slowly.
- Deuterium ^{2}H has same spectra as hydrogen ^{1}H but slightly shifted.
  - Abundance of ^{2}H: Strength of ^{2}H spectral line compared with ^{1}H line.

400km/s=d wavelegnth = wl/750



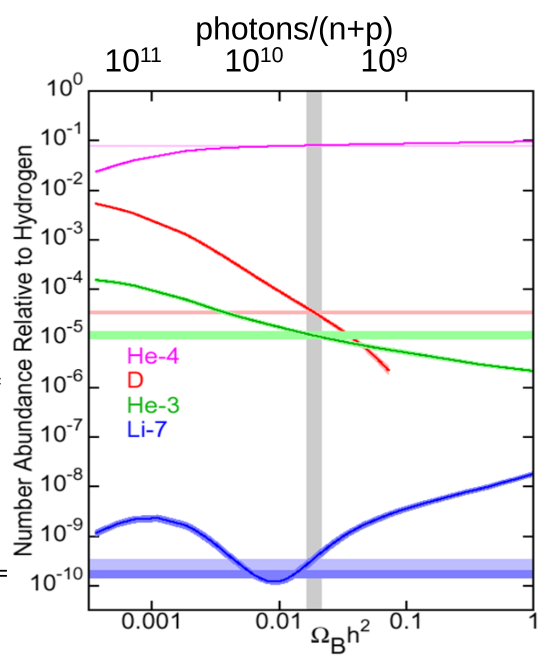
O'Meara, et al., 2001, ApJ 552, 718.

Results

- Horizontal bars are measurements.
- Lines are models for differing amounts of photons/(n+p)
  - The temperature of the radiation from the BB tells us the number of photons.

1. How many ^{1}H nuclei are there for every ^{2}H nucleus according to the measurements?
2. The model for photons/(n+p) = 10^{11} is inconsistent with the measurements. The measured ^{4}He is too ___.
   A. High
   B. Low

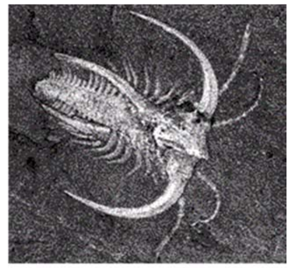
- Measurements are consistent with models for photons/(n+p) = 4×10^{10}.



Ned Wright's Cosmology Notes

Examining the fossil, conclusions

- Calculations, which contain U expanding and nuclear physics, yield abundances of ^4He, ^7Li, ^2H, & ^3He. The only free parameter is number density of n and p.
- Measured and calculated abundances are consistent.
  - 7Li is slightly off
- Understanding of BB (and nuclear physics) is confirmed.
- Surprise: Most of neutrons and protons are not in stars. Lots in gas between galaxies. Location of about 50% is not known.



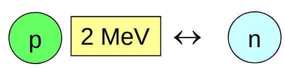
Fossil from Burgess Shale

Objectives

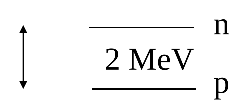
- Why did the abundance of neutrons change before the "fossil was laid down" and not afterwards?
- #n/#p does not change when neutrons are in a stable nucleus. (Done on Mon)
- How do free neutrons and protons change identity? How does the temperature of the radiation affect this process? (Now)

Changing free neutrons & protons

- Neutrons were free before nuclei formed at 3min.
- Proton changes into neutron
  - $p + e^- + \text{energy} \rightarrow n + \nu$
  - Need 2MeV of energy
- Neutron changes into proton
  - Positron must hit neutron
  - $n + e^+ \rightarrow p + \text{energy} + \nu$
  - Happens spontaneously in 1000s (17min)
  - $n \rightarrow p + e^- + \text{energy} + \nu$



- 1electron-Volt is the typical energy of a chemical reaction.
- 1.5eV is the energy a battery gives to one electron.
- $1\text{eV} = 1.6\times10^{-19}\text{J}$
- 1MeV is the typical energy of a nuclear reaction.

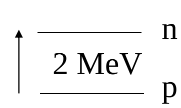


Changing free neutrons & protons

- Case of equilibrium: There are many collisions between neutrons and positrons and between protons and neutrons.
  - This is the case when the density of electrons and positrons was high.
  - When density of electrons and positrons was lower, collisions became too infrequent to maintain equilibrium. Neutrons decayed into protons.
- In equilibrium, neutrons change into protons and protons change into neutrons. Change occurs by rules of probability.
- A collision of a neutron or a proton occurs. What is the result of the collision?

$$(\text{Probability of neutron})/(\text{Probability of proton}) = e^{-E/(kT)}$$

  - E is energy it takes to change a p into a n (2MeV)
  - T is the temperature. kT is average energy available.

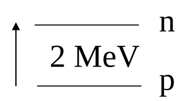


$E/(kT)$	(Prob. n) /(prob. p)
0.01	0.99
0.1	0.9
1	0.37
3	0.05
10	0.00005

Changing free neutrons & protons

(Probability of neutron)/(Probability of proton) $= e^{-E/(kT)}$

- E is energy it takes to change a p into a n (2MeV)
- T is the temperature. kT is average energy available.



1. When the average available energy is much higher than energy needed to make a neutron, the probability of getting a neutron is ___ probability of getting a proton.
   A. About the same as
   B. Much less than
   C. Much more than
2. In this case, the number of n is ___ the number of protons.
3. When the average available energy is much lower than energy needed to make a neutron, the probability of getting a neutron is ___ probability of getting a proton. (Same foils.)
4. In this case, the number of n is ___ the number of protons.
5. Case in problem 1 is when universe was ___ than case in #3.
   A. Younger
   B. Older

$E/(kT)$	(Prob. n)/(prob. p)
0.01	0.99
0.1	0.9
1	0.37
3	0.05
10	0.00005

$p + e^- + \text{energy} \rightarrow n + \nu$

$n + e^+ \rightarrow p + \text{energy} + \nu$

- When the temperature of the radiation was hot and the average energy of was much bigger than 2 MeV, neutrons could change into protons as easily as protons into neutrons.
- As universe cooled, n $\rightarrow$ p occurs more often than p $\rightarrow$ n, and p becomes more abundant than n.