Formation of Helium in the BB

- A fossil is a remnant or trace of the past. Amount of helium is a fossil from the Big Bang.
  - Mass He/Mass H = 1:3
  - neutrons/protons = 1:7

- Three snapshots
  - 0.001s. n/p = 1:1
  - 3min. n/p = 1:7
  - Now. n/p = 1:7

---

- Please rate your class at
  - rateyourclass.msu.edu
  - Closes on May 8th.
- Open house at MSU Telescope
  - See the Orion Nebula, the moon, & other wonders through the 24" telescope
  - Friday and Saturday, May 1 and 2, from 9:30pm - 11pm, weather permitting
  - Observatory is on Farm Lane & Forest Rd (south of campus)

- Homework 7
  - Due 6:00 pm on Tues, April 28th, just before Missouri Club
- Missouri (Show Me) Club
  - Room 1415, today, 7:00-8:00pm
- Final Exam
  - Wed, May 6th, 3:00-5:00
  - Room 1410 (our classroom)
  - One 8½ × 11 cheat sheet.
  - Covers entire course with more emphasis on galaxies & cosmology.
1. At the present time, n:p=1:7. Where are all of those neutrons?
   A. in $^4$He (helium with 2p & 2n)
   B. in $^{16}$O (oxygen with 8p & 8n)
   C. in $^{12}$C (carbon with 6p & 6n)

Neutrons/protons when U was 0.001s old

- 0.001s
  - Temperature = 400 BK
  - E=40 MeV is much greater than cost to be a neutron
  - n:p = 1:1

1. Later (at 0.01s) the temperature of the U is ___.
   A. warmer
   B. cooler
   C. same

2. At later times (0.01s), n/p is ___.
   A. higher
   B. lower
   C. same
Production of deuterium

- Production of deuterium (hydrogen with one neutron)
  - \( n + p \leftrightarrow ^2H + \text{energy} \)
  - If the universe is too hot, radiation has so much energy that deuterium is broken apart.
- Once deuterium forms and becomes stable, helium forms quickly, and all of the neutrons are locked in \(^4\text{He}\).
- 0.001s
  - Temperature = 400 BK
  - \( E=40 \text{ MeV} \) is much greater than cost to be a neutron
  - \( n:p = 1:1 \)
  - Deuterium is easily broken apart.

1. If deuterium & \(^4\text{He}\) could form at 0.001s, how much helium and hydrogen would form from 16 nucleons? Mass \(^4\text{He}\) and mass H are
   A. 0 and 16
   B. 8 and 8
   C. 16 and 0
   D. 4 and 12

2. If deuterium & \(^4\text{He}\) form later, does ___ helium forms.
   A. less
   B. more
   C. same amount of
Neutrons/protons when U was 3min old

- As universe cools, n/p drops because the cost of being a neutron is more and more expensive.
- 3 min
  - Temperature = 1 BK
  - E=0.1MeV is much less than cost to be a neutron
  - n:p = 1:7
- Production of deuterium (hydrogen with one neutron)
  - \( n + p \leftrightarrow ^2H + \text{energy} \)
- At 3min, deuterium becomes stable. Neutrons get locked up in \(^4\text{He}\).

1. How much helium and hydrogen would form from 16 nucleons?
   Mass \(^4\text{He}\) and mass \(^1\text{H}\) are:
   A. 0 and 16
   B. 8 and 8
   C. 16 and 0
   D. 4 and 12

- 25% of mass is in \(^4\text{He}\) and 75% of mass is in \(^1\text{H}\).
Neutrons/protons at the present time

- Now, 13Byr
  - Temperature = 2.7K
  - E=tiny
  - n:p = 1:7
- Production of deuterium (hydrogen with one neutron)
  - \[ n + p \leftrightarrow ^2\text{H} + \text{energy} \]
- At 3min, deuterium becomes stable. Neutrons get locked up in \(^4\text{He}\).
- 25% of mass is in \(^4\text{He}\) and 75% of mass is in \(^1\text{H}\)
- Neutrons are safely in helium.
1. Amount of \(^4\text{He}\) has increased slightly because
   A. helium is made in stars
   B. neutrons are still changing into protons.

"Collecting the Fossil"

- \(^4\text{He}, ^7\text{Li}, ^2\text{H}, \text{ & } ^3\text{He}\) are made in BB.
  - Lots of \(^4\text{He}\)
  - Trace amounts of \(^7\text{Li}, ^2\text{H}, \text{ & } ^3\text{He}\). 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\text{H} has same spectra as hydrogen ^1\text{H} but slightly shifted.
  - Abundance of ^2\text{H}: Strength of ^2\text{H} spectral line compared with ^1\text{H} line.