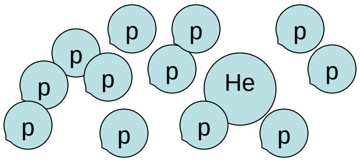
Helium Production in Big Bang—9 Nov

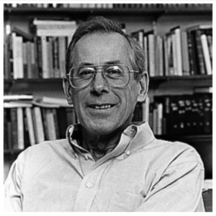
- A fossil is a remnant or trace of the past. What is a fossil from the Big Bang?
  - There are 7 protons for every neutron
  - The surface of the sun is 25% He and 75% H.
- What does that fossil tell about the BB?



Fossil from Big Bang

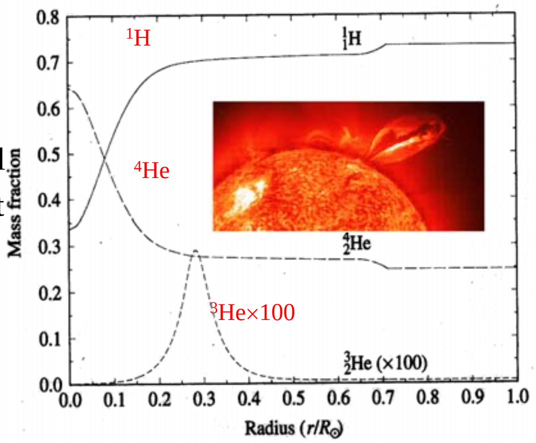
Fossil from Burgess Shale

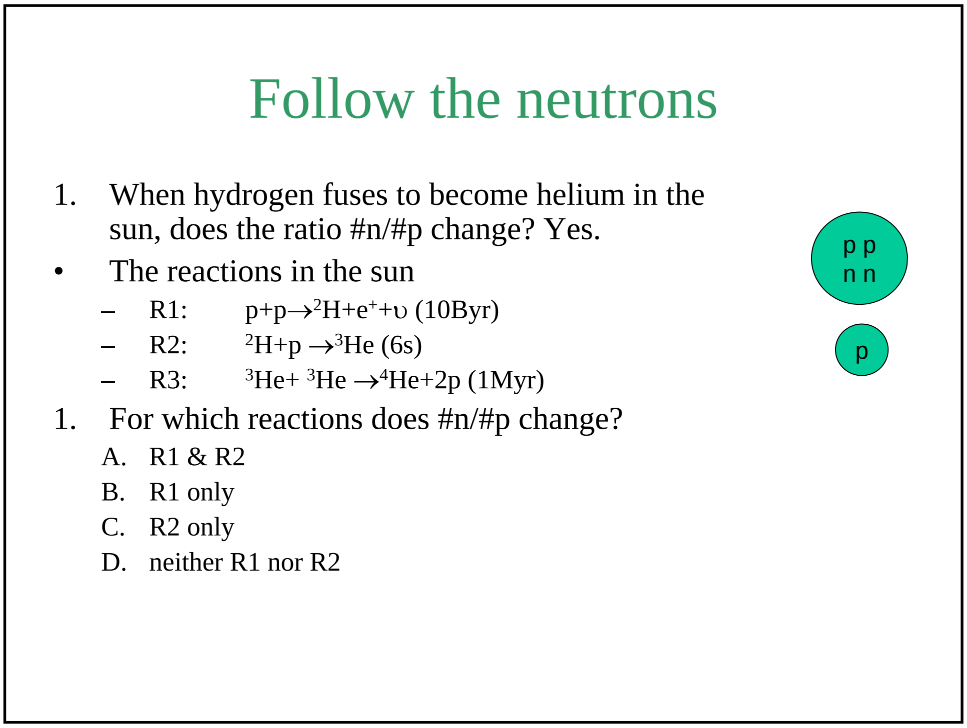
Helium Formed When Universe Was 3 Minutes Old



Jim Peebles

- How & where were the elements made?
  - Carbon, Iron, Calcium in stars
  - Hydrogen is primordial
  - Helium is too abundant to have been made in stars.
  - Helium was made at 3min.



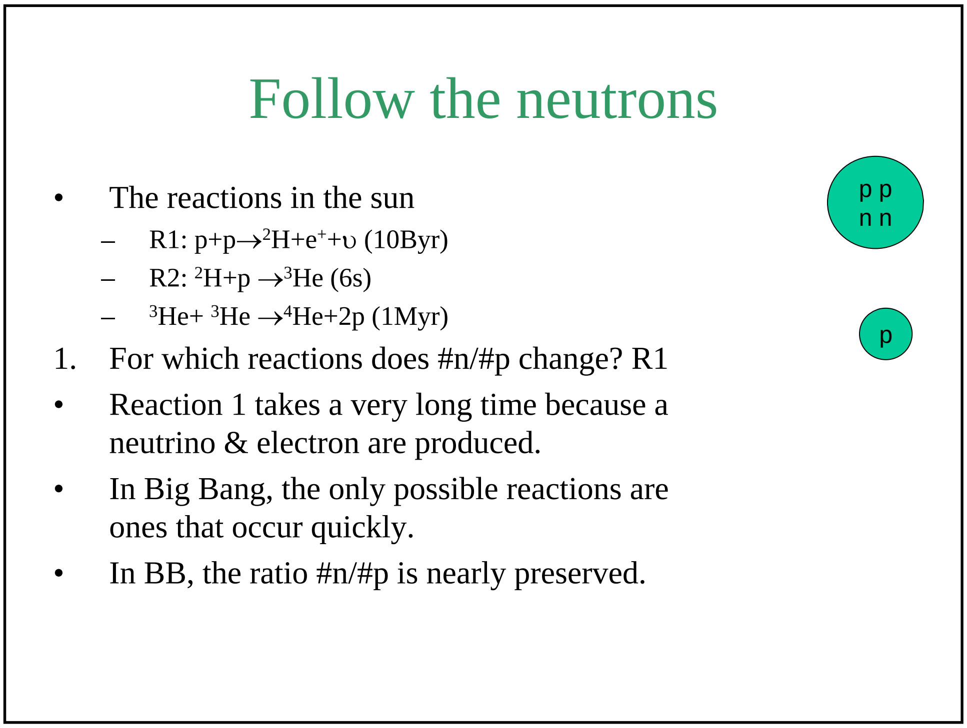


Follow the neutrons

1. When hydrogen fuses to become helium in the sun, does the ratio #n/#p change? Yes.

- The reactions in the sun
  - R1: $p+p \rightarrow {}^{2}H+e^{+}+\upsilon$ (10Byr)
  - R2: ${}^{2}H+p \rightarrow {}^{3}He$ (6s)
  - R3: ${}^{3}He+{}^{3}He \rightarrow {}^{4}He+2p$ (1Myr)

1. For which reactions does #n/#p change?
   - A. R1 & R2
   - B. R1 only
   - C. R2 only
   - D. neither R1 nor R2



Follow the neutrons

- The reactions in the sun
  - R1: $p+p \rightarrow {}^{2}H+e^{+}+\upsilon$ (10Byr)
  - R2: ${}^{2}H+p \rightarrow {}^{3}He$ (6s)
  - ${}^{3}He+{}^{3}He \rightarrow {}^{4}He+2p$ (1Myr)

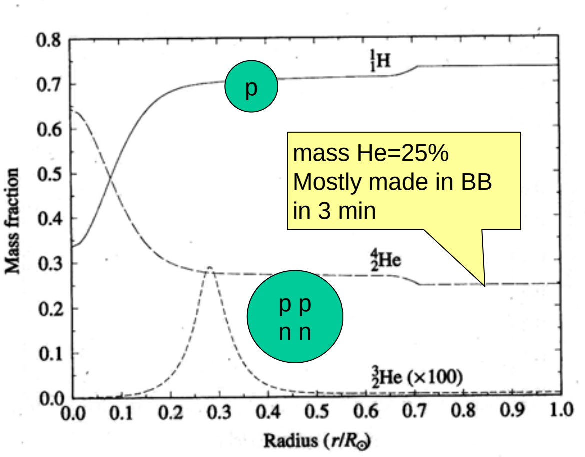
1. For which reactions does #n/#p change? R1

- Reaction 1 takes a very long time because a neutrino & electron are produced.
- In Big Bang, the only possible reactions are ones that occur quickly.
- In BB, the ratio #n/#p is nearly preserved.

#n/#p at the present time

- In the outer parts of the sun, the material is nearly primordial.
- He is 25% of the mass, H is 75%. 12 <u>H atoms for every He atom</u>
  - Mass He = 4
  - Mass H = 12
  - Total mass = 16

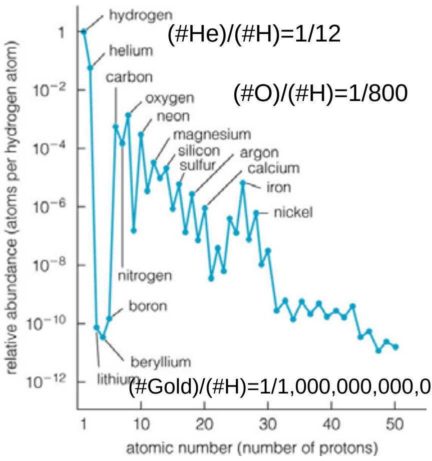
1. #n / #p =
   a. 1:1
   b. 1:12
   c. 2:14
   d. 4:12
   e. 2:3



mass He=25%
Mostly made in BB
in 3 min

Follow the neutrons

- #n/#p=2/14=1/7 now
- Processing in stars changes #n/#p slightly.
  - #n/#p in H and O
    - 8n/(800p+8p)=1/101
- <u>#n/#p has been 1/7 from 3min to now.</u>
- How do neutrons change into protons and protons very quickly?



(#He)/(#H)=1/12

(#O)/(#H)=1/800

(#Gold)/(#H)=1/1,000,000,000,000

Changing neutrons & protons

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

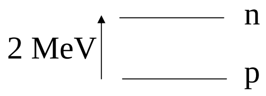
- 1electron-Volt is the typical energy of a chemical reaction.
- 1.5eV is the energy a battery gives to one electron.
- $1\text{eV} = 1.6\times10^{-19}\text{J}$
- 1MeV is the typical energy of a nuclear reaction.

p 2 MeV ↔ n

Changing neutrons & protons in BB

- Radiation in the universe can supply energy to change n into p.
  - If the energy of a photon is much more than 2 MeV, then the extra energy needed to be a neutron is no barrier.
- At present
  - 2.7K; E=eV/4000.
  - Not enough energy for p→n.
  - n:p = 1:7
- At 3 min
  - 1 BK; E=0.1MeV
  - Not enough energy for p→n. n→p does occur, because energy is released.
  - n:p = 1:7
- At 0.001s
  - 400 BK; E=40 MeV.
  - More than enough energy for p→n.
  - n:p = 1

p 2 MeV ↔ n



Changing neutrons & protons in BB

- Radiation in the universe can supply energy to change n into p.
- At present
  - Not enough energy for n→p.
  - n:p = 1:7
- At 3 min
  - Not enough energy for n→p. p→n does occur, because energy is released.
  - n:p = 1:7
- At 0.001s
  - More than enough energy for n→p.
  - n:p = 1

1. When U was 3 min old, there were 2n and 14p. I want to make them into H & ^{4}He without free neutrons left over. I make
   A. 16 H
   B. 4 ^{4}He
   C. 14 H, ^{4}He
   D. 12 H, 2 ^{4}He
   E. 12 H, ^{4}He

p 2 MeV ↔ n

Changing neutrons & protons in BB

- Radiation in the universe can supply energy to change n into p.
- At present
  - Not enough energy for n→p.
  - n:p = 1:7
- At 3 min
  - Not enough energy for n→p. p→n does occur, because energy is released.
  - n:p = 1:7
- At 0.001s
  - More than enough energy for n→p.
  - n:p = 1

1. Suppose at 0.001s after the BB, it was possible to make ^{4}He. I have 8p and 8n. I want to make them into H & ^{4}He without free neutrons left over. I make
   A. 16 H
   B. 4 ^{4}He
   C. 14 H, ^{4}He
   D. 12 H, 2 ^{4}He
   E. 12 H, ^{4}He

p 2 MeV ↔ n

Pathway: formation of deuterium

- ^{4}He cannot form from n & p directly.
- ^{2}H, deuterium, must form first.
  - When U was too hot, deuterium gets destroyed as soon as it forms.
  - At 3min, deuterium becomes stable. Then ^{4}He forms.
- Amount of ^{4}He depends on nuclear physics of deuterium.
  - If deuterium were stable at 0.001s, when n:p=1, there would be no hydrogen, only ^{4}He.
  - If deuterium became stable at 1hr, then n:p=0, there would be no helium, only H.
- Other reactions.

$^2H + {}^2H \rightarrow {}^3H+p$

$^2H + {}^2H \rightarrow {}^3He+n$

$^3H + {}^2H \rightarrow {}^4He+n$

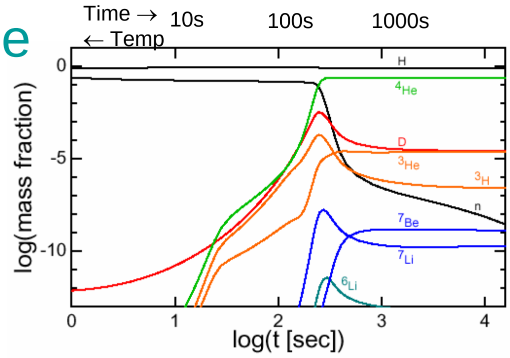
$^3He + {}^2H \rightarrow {}^4He+p$

$\ldots \Leftrightarrow {}^7Li$

  - Besides 4He, also produce ^{2}H, ^{3}He, ^{7}Li.

How ^{4}He is made

- What changed during the first hour?
  - At 1 s, neutrons & protons; minute amount of ^{2}H (D).
  - Ratio n/p drops slowly
  - ^{2}H, as well as ^{3}H and ^{3}He increases staring at 30s.
  - ^{4}He increases
  - At 200 s, ^{2}H, ^{3}H, and ^{3}He drops. ^{4}He stays high.
  - At 10,000s (3hr), U is primarily ^{1}H & ^{4}He with trace amounts of others.



- Need answers
  - Why does n/p drop even before 10s? Very few neutrons are being incorporated in ^{2}H.
  - What is beginning to happen at 30s? Why does it start then?