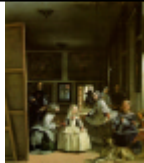
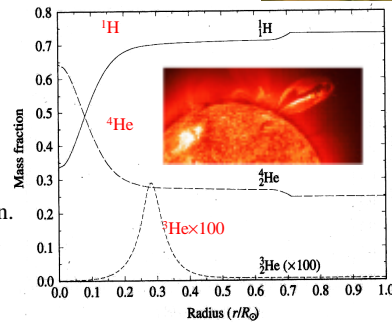


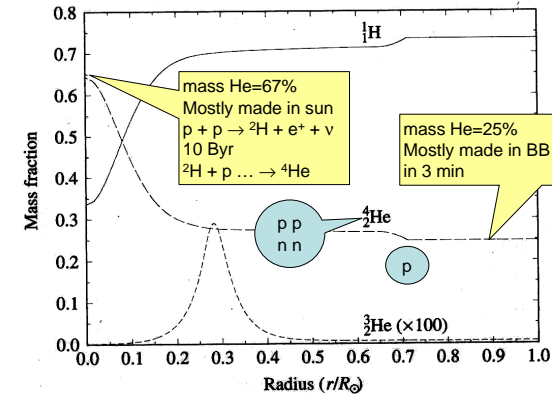
## Helium Formed When Universe Was 3 Minutes Old—2 Nov



- How & where are the elements made?
- Answer before discovery of radiation from BB:
  - Carbon, Iron, Calcium in stars
  - Hydrogen is primordial
  - Helium is too abundant to have been made in stars.
- Helium was made at 3min.
- Observations of  $^4\text{He}$  (and  $^3\text{He}$ ,  $^7\text{Li}$ ,  $^2\text{H}$ ) agree with calculations using Big Bang & nuclear physics

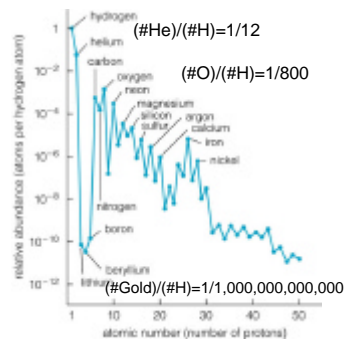


## Helium in the Sun



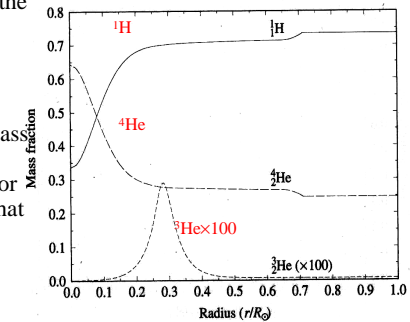
## Helium Abundance is High

- Helium is much more abundant than every element but hydrogen
  - Abundance He = #He/#H
  - Abundance He = 1/12
  - Abundance O = 1/800
  - Abundance Au = 1/trillion
- Abundance of stellar born is 1/800 or less. Helium is born in BB.



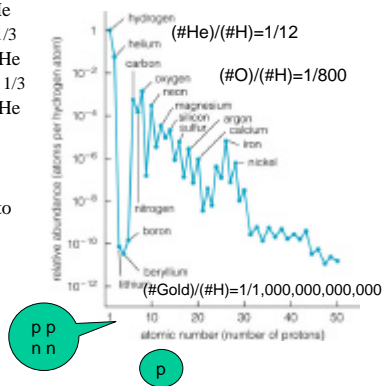
## Key is to follow the neutrons

1. When hydrogen fuses to become helium, does the ratio #n/#p change? Same question for  $^4_2\text{He} \rightarrow ^{12}_6\text{C}$ .
2. The mass in helium is about 25%, and the mass in hydrogen is 75%. How many H nuclei for every He nucleus? What is #n/#p?



## Follow the neutrons

- Try 2 H nucleus for every He
  - MassHe/MassH=4/2; not 1/3
- Try 10 H nucleus for every He
  - MassHe/MassH=4/10; not 1/3
- Try 12 H nucleus for every He
  - MassHe/MassH=4/12=1/3
- #n/#p=2/14=1/7 now
- #n/#p=1 at 1 ms
- How do neutrons change into protons?



## Changing neutrons & protons

- Proton changes into neutron
    - $p + e^- + \text{energy} \rightarrow n + \nu$
    - $E = 2\text{MeV}$
  - Neutron changes into proton
    - $n + e^+ \rightarrow p + \text{energy} + \nu$   
(positron must hit neutron)
    - $n \rightarrow p + e^- + \text{energy} + \nu$   
(happens spontaneously in 1000s)
1. A proton and a neutrino change into a neutron. What else must be produced?
  2. Why do protons not change into neutrons today?

