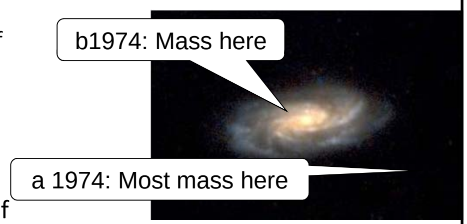
Helium Production in Big Bang Weighing a Galaxy—12 Nov

- Finish helium production.
- Four most important discoveries in cosmology
  - Hubble's Law, expansion of universe 1929
  - Radiation from BB 1965
  - Dark matter 1930s, 1970s
  - Accelerated expansion 1998
- What is the mass of a galaxy?
  - Answer before 1974: Mass is that of stars & gas
  - Actual answer: Most mass is not that of star & gas
  - Most mass is dark
  - Dark mass is less concentrated.
- How to measure mass (today)
- Mass of NGC3672
- How do measurements of the mass of NGC3672 imply the presence of dark matter.

- 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.
  - Long assignment. Start early.
- Test 3 is on Mon, 22 Nov
  - Covers dark matter.



NGC 3672
www.astro.princeton.edu/~frei/Gcat_htm/Catalog/CJpeg/n3672.jpg

Objectives

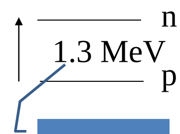
- Why did the abundance of neutrons change before the "fossil was laid down" and not afterwards?
- #n/#p does not change when neutrons are in a stable nucleus. (Done on Mon)
- How do free neutrons and protons change identity? How does the temperature of the radiation affect this process? (Wed & today)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

Changing free neutrons & protons in BB

- Radiation in the universe can supply energy to change n into p.
  - More precisely, to supply energy to electrons and positrons to change n into p.
- At 0.001s (time for sound to travel 1ft in air)
  - T=3000 GK (1gigaK = 10^9K); kT=260 MeV.
  - More than enough energy for p→n. (Bill Gates era)
  - n:p = 1

1. At 0.5s, T=50GK, and kT=4MeV. Is the universe in the Bill Gates era or the Corey Trammell era, where n/p is ___.
   A. BG. approximately 1.
   B. BG. small.
   C. CT. approximately 1.
   D. CT. small.
2. At 5s, T=10GK, and kT=0.9MeV. Same question.

- At 5s, 10BK, and kT=0.9MeV. n/p=0.2.
- When T is between 10BK and 3BK, the density drops so that
  - number of collisions falls & neutrons and protons are no longer in equilibrium.
  - Protons no longer change into neutrons. Neutrons decay into protons.



Correction

$E/(kT)$	(Prob. n) /(prob. p)
0.01	0.99
0.1	0.9
0.3	0.74
1	0.37
3	0.05
10	0.00005

Pathway: formation of deuterium

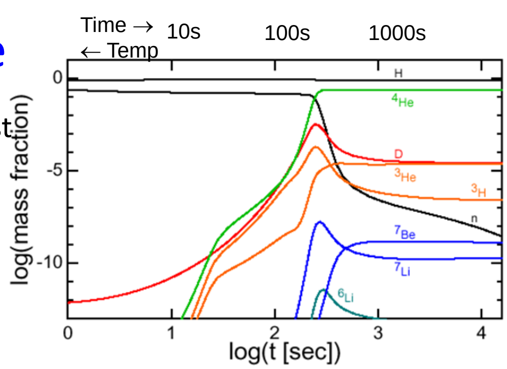
- Formation of ^{4}He requires ^{2}H, deuterium, as a intermediate step.
- Deuterium breaks apart if the temperature is too high.
  - When U was too hot, deuterium gets destroyed as soon as it forms.
  - At 3min, deuterium becomes stable. Then ^{4}He forms.
- Amount of ^{4}He depends on nuclear physics of deuterium.
- Deuterium becomes stable when n:p=1:7. Get 12p for every ^{4}He.
  - 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 nuclear reactions

- Reactions that yield ^4He
  - $^2H + ^2H \rightarrow ^3H + p$
  - $^2H + ^2H \rightarrow ^3He + n$
  - $^3H + ^2H \rightarrow ^4He + n$
  - $^3He + ^2H \rightarrow ^4He + p$
- A bunch of reactions produce ^7Li
- Final products
  - ^4He
  - ^2H (Some deuterium never has a chance to collide & change into anything else.)
  - ^3He
  - No ^3H. It is unstable.
  - ^7Li

How ^4He is made

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

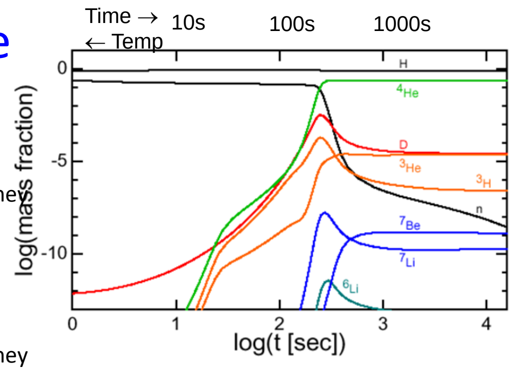


1. At the end, there are ___ kg of hydrogen for every kg of ^7Li.
   A. -10
   B. 10^{10}
   C. 10^{-10}

- 10M tons of H for every kg of ^7Li.

How ^{4}He is made

1. Why does abundance of free neutrons drop slowly at first?
   A. They change into protons.
   B. Deuterium becomes stable, and they become incorporated into nuclei.
2. Why does abundance of free neutrons drop steeply at 200s?
   A. There is enough time for them to decay into protons.
   B. Deuterium becomes stable, and they become incorporated into nuclei.
3. When does #n/#p stop changing? Hint: Where are the neutrons?
   A. 10s
   B. 30s
   C. 100s
   D. 300s
   E. 1000s.



4. Why does #n/#p stop changing significantly?
   A. There are no more neutrons.
   B. The temperature of the universe does not cool any more.
   C. n→p does not occur inside stable nuclei.

Summarizing questions

1. What are the fossils (something that can be examined) from the universe at 3 min?
2. The amount of helium in the sun depends on the properties of deuterium. If deuterium is less tightly bound, would there be more or less helium on the surface of the sun?