Weighing a Galaxy—11 Nov

- Schedule
  - Finish "Helium in the Big Bang"
  - What are galaxies made of? (Today & Fri)
- Hwk 8 is due Mon, 16th.
- Hwk 9 is due Fri, 20th.
  - Questions about measuring the mass of galaxies.
  - No late papers. Answers will be put on angel after class.
- Observing on Wed & Thurs, 18th & 19th. Extra credit.
- Test 3 is on Mon, 23rd.
  - Covers material through "What are galaxies made of?"
- No class on Wed, 25th.

Nuclear physics in the Big Bang

I. When the temperature of the radiation was hot and the energy of was much bigger than 2 MeV, neutrons could change into protons as easily as protons into neutrons.

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

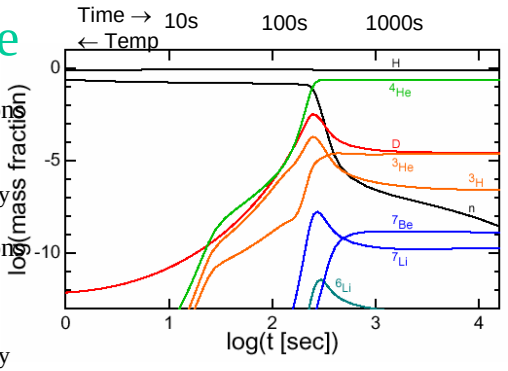
$$n + e^+ \rightarrow p + \text{energy} + \nu$$

As universe cooled, $n \rightarrow p$ occurs more often than $p \rightarrow n$, and p becomes more abundant than n.

II. Formation of ^{4}He requires deuterium as a intermediate step. Deuterium breaks apart if the temperature is too high.

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?
   A. 10s
   B. 30s
   C. 100s
   D. 300s
   E. 1000s.



1. 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.

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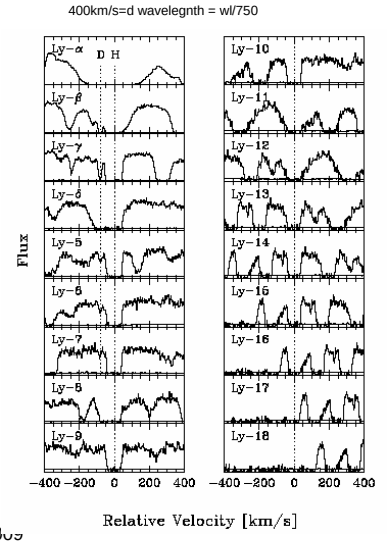
"Collecting the Fossil"

- ^{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 when very little of material had been processed through stars.
  - Dwarf galaxies, where material is processed through stars very slowly.
- Deuterium ^{2}H has same spectrum as hydrogen ^{1}H but slightly shifted.
  - Abundance of ^{2}H: Strength of ^{2}H spectral line compared with ^{1}H line.



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

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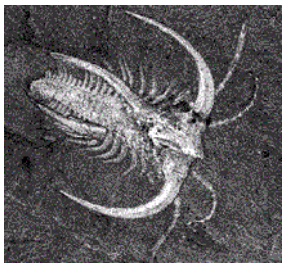
Examining the fossil, conclusions

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



Fossil from Burgess Shale

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?

Galaxies

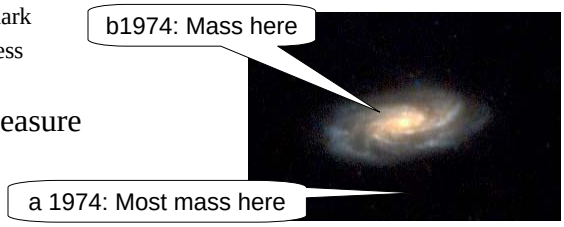
- The Milky Way is our galaxy.
  - The sun is halfway from the center of the Milky Way.
  - We see the Milky Way as a band of light.
- Spiral galaxies are made of
  - billions of stars
  - gas
  - dust
  - dark matter
- The sky is covered by distant galaxies.

Weighing a Galaxy

- 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.
- Today: How to measure mass

Fritz Zwicky 1898-1974
www.astrosurf.org/lombry/Images/zwickyf.jpg

Vera Rubin 1928-
cwp.library.ucla.edu/images/rubin.1.jpg

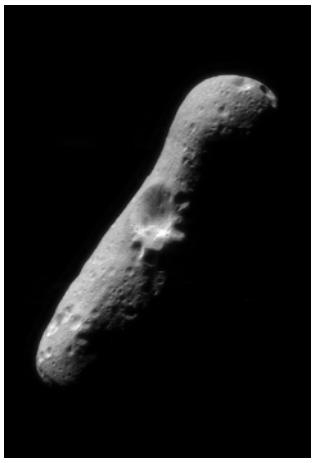


NGC 3672
www.astro.princeton.edu/~frei/Gcat_htm/Catalog/CJpeg/n3672.jpg

Weighing Eros


- Near Earth Rendezvous (NEAR) orbited the asteroid Eros (and landed). http://near.jhuapl.edu
- Eros
  - 20mi long, 8mi wide (size of Lansing)
- Gravity is 1000 times weaker
  - You can leap 1000 times farther
    - $\frac{1}{2}v^2 = g\,h$
  - Speed limit is 20mph
    - $v^2 = g\,R$
- On Earth, a ball dropped 1m takes 0.45s. How long would that take on Eros?
    - $\frac{1}{2}v^2 = g\,h$; $v = g\,t$; $t = (2h/g)^{1/2}$
    - $t = 0.45\text{s}\ (1000)^{1/2} = 14\text{s}$

1. How can you measure the mass of Eros with the satellite (without landing)?



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Weighing the Sun

- To find mass of sun, measure period T & size R of a planet's orbit. Kepler's 3rd Law:

  $M = R^3 / T^2$ for R in AU, T in years, and M in solar masses.

2. Under influence of the gravity of the sun, a planet moves a given distance. If the time is short, the mass of the sun is
   A. greater.
   B. less.

Mass	Test object	Motion	Behavior if more massive
Eros / Earth	A ball	Drop of 1m	Time is shorter
Sun	Earth	An orbit	
Galaxy			

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Weighing a galaxy

- To find mass of sun, measure period T & size R of a planet's orbit. Kepler's 3rd Law:

  $M = R^3 / T^2$ for R in AU, T in years, and M in solar masses.

2. Under influence of the gravity of the sun, a planet moves a given distance. If the time is short, the mass of the sun is greater. Write an equivalent statement for the galaxy NGC 3672.

Mass	Test object	Motion	Behavior if more massive
Eros / Earth	A ball	Drop of 1m	Time is shorter
Sun	Earth	An orbit	Period is shorter
Galaxy	Cloud of gas		

Use Doppler effect

- Kepler's Law needs modification since period of sun's motion around Milky Way is 200 Myr.

  $Mass = R^3 / T^2 = R (R/ T)^2$

  $Mass = R\ v^2$ (w/o constants)

  $Mass = 233\ R\ v^2\ M_{sun}$ (v in km/s and R in pc)
- Doppler effect for measuring speed.
  - No need to wait to see motion.
  - Speed is imprinted in the light.