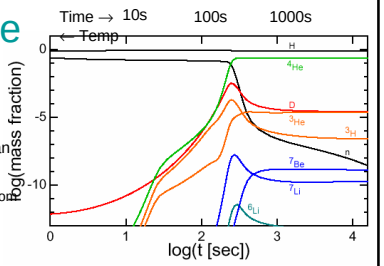
Nov

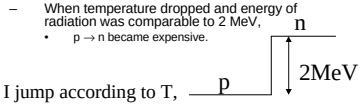
- Finish formation of He
- Weighing galaxies

How ^{4}He is made

- Why does n/p drop even before 10s?
- Reaction changes n & p.
  - p+e$^-$+E $\leftrightarrow$ n+ν
  - E = 2MeV
- Probability for being a proton (rather than a neutron) is
  - e^(-2MeV/(kT))
  - 2 MeV = energy cost to make a proton from a neutron
  - k T = Energy available at T, k is Boltzmann's constant
  - When kT is much bigger than 2MeV, probabilty = 1
    - When temperature was high and energy of radiation was much greater than 2 MeV,
    - p $\rightarrow$ n and n $\rightarrow$ p at same rate.
  - When kT is 1/5 of 2MeV, probabilty = e^(2MeV/(1/5*2MeV)) = e^-5 = 0.0007
  - When temperature dropped and energy of radiation was comparable to 2 MeV,
    - p $\rightarrow$ n became expensive.



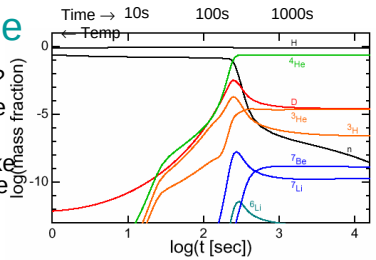
- Need answers
  - Why does n/p drop even before 10s? Neutrons are not being incorporated in ^{2}H.
  - What is starting up at 30s? Why does it start then?



I jump according to T,
If I hand on bottom, I am a p; on top, I am a n.

How ^{4}He is made

- What is starting up at 30s?
- Deuterium becomes stable
  - p + n $\rightarrow ^2$H
- Why does this reaction take seconds and not 10Byr like
  - p + p $\rightarrow ^2$H+e$^+$+ν
- Remaining reactions
  - ^{2}H + ^{2}H $\rightarrow ^3$H+p
  - ^{2}H + ^{2}H $\rightarrow ^3$He+n
  - ^{3}H + ^{2}H $\rightarrow ^4$He+n
  - ^{3}He + ^{2}H $\rightarrow ^4$He+p
  - … $\Leftrightarrow ^7$Li



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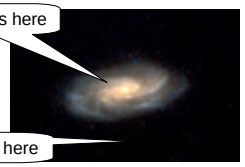
Weighing a Galaxy—7 Nov

- 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

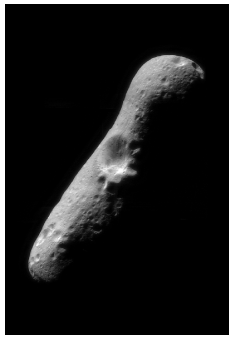


NGC 3672
www.astro.princeton.edu/~frei/Gcat_htm/Catalog/CJpeg/n3672.jpg

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?
  - $\frac{1}{2}v^2 = g\,h$; $v = g\,t$; $t = (2h/g)^{1/2}$
  - $t = 0.45s\,(1000)^{1/2} = 14s$

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



Weighing the Sun

- To find mass of sun, measure period T & size R of a planet's orbit.
  - Kepler's 3rd Law
    $GM = 4\pi^2 R^3 / T^2$
  - $M = R^3 / T^2$ 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 is ___.

Mass	Test object	Motion	Behavior if more massive
Sun	Earth	An orbit	
Eros			
Earth			
Galaxy			

Weighing a Galaxy

- To find mass of sun, measure period T & size R of a planet's orbit.
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  - $M = R^3 / T^2$ for R in AU, T in years, and M in solar masses.

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

Mass	Test object	Motion	Behavior if more massive
Sun	Earth	An orbit	Year is shorter
Eros			
Earth			
Galaxy			