ASTR 1020: Stars & Galaxies

April 21, 2008

- Reading: Chapter 23, sections 23.2-23.3 .
- *MasteringAstronomy* Homework on The Fate of the Universe is due April 30th.
- 2 more extra credit opportunities at Fiske Planetarium this week and next!

Astronomy Picture of the Day

IC 2948: The Running Chicken Nebula
Credit & Copyright: Steve Crouch
Explanation: Bright nebulae abound in and around the expansive southern constellation of Centaurus, Stardust Melody.

Last Lecture

- Chapter 22, Section 4: Dark Matter and the fate of the Universe

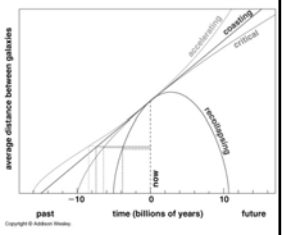
Today

- Chapter 23: The Creation of the Universe

(the creation of all matter, light and energy)

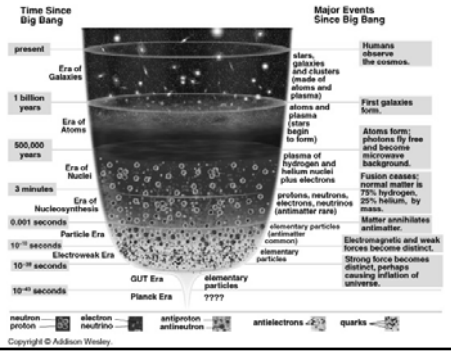
Important Diagram

- "Average distance between galaxies"
  = 1 / expansion factor
  =1 / (1+z)
- NOW is fixed in time (z=0)
- Hubble constant NOW sets the slope of the line = how fast the universe is expanding NOW



Big Bang= when distance is zero; z=infinity

Chapter 23: In the VERY Beginning

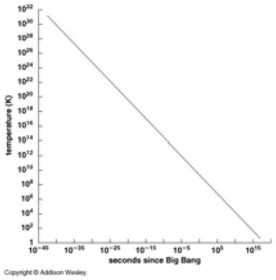


Hot stuff!

Everything in the Universe was hotter at earlier times, and then cooled as it expanded

The temperature at the earliest times was more than the energy we create in particle accelerators

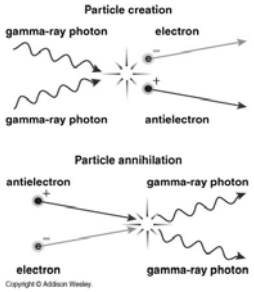
Cosmology at the earliest times is explored via particle physics!



Matter and Energy

- $E=mc^2$
- Matter and energy are the same, can transform from one to another

Matter + antimatter ← → photons



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The Planck Era

- Before the first 10^{-43} seconds!
- Four Fundamental forces: gravity, electromagnetism, weak nuclear (mediates nuclear reactions) and strong nuclear (holds atomic nucleus together) forces are "united" (work as one force)
- No complete theory to describe how this works…

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Clicker Question

Which of the four forces keeps you from sinking to the center of the Earth?

A. Gravity
B. Electromagnetism
C. Strong Force
D. Weak Force

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Clicker Question

Which of the four forces keeps you from sinking to the center of the Earth?

A. Gravity
B. **Electromagnetism**
C. Strong Force
D. Weak Force

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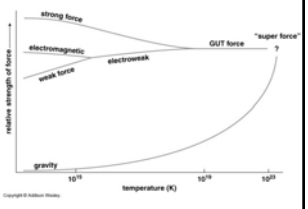
The Grand Unified Theory Era (GUT Era)

- Up to 10^{-38} sec
- Temperatures higher than can be created in particle accelerators
- Fundamental forces become distinct as the universe cools



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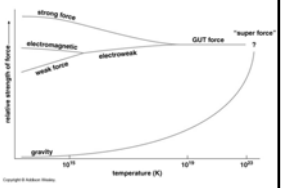
INFLATION

- As strong force becomes distinct, a huge amount of energy is released
- Universe INFLATES: atomic nucleus size becomes solar system size (expands by a factor of 10^{30}) in 10^{-36} sec … but DOES NOT COOL
- Weird- but LOTS of evidence for INFLATION



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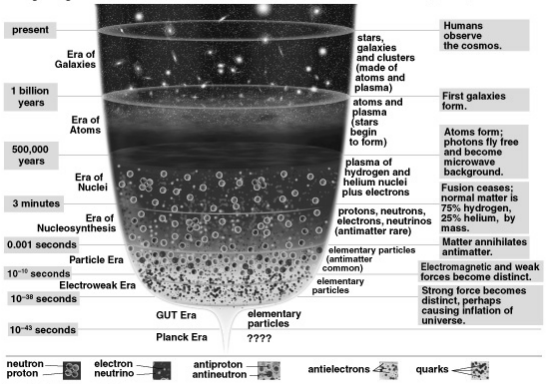


The Particle Era

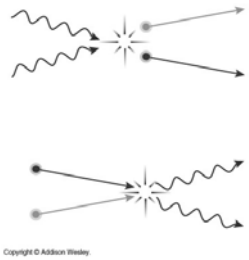
- Universe still hot: 10^{15} to 10^{12} K
- Particles now exist: electrons, protons; anti-protons, anti-electrons, neutrinos etc.
- Particle soup! Particles and photons/energy created and annihilated

Matter and Anti-matter

- Protons slightly outnumber anti-protons.

→ At the end of the Particle Era, universe contains some matter!

- Universe today: 1 billion photons (light) to 1 leftover proton (matter)



Clicker Question: What happens when a proton collides with an antiproton?

a) They repel each other
b) They fuse together
c) They convert into two photons
d) They convert into neutrinos

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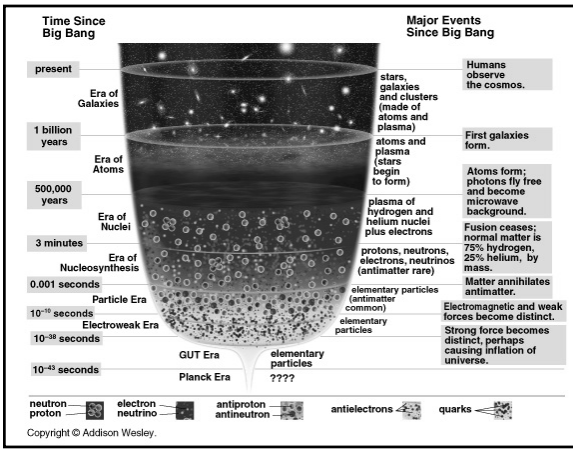
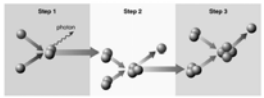


Era of Nucleosynthesis (fusion)

- Matter particles are "frozen out": no longer spontaneously generated to/from photons
- Temperatures hot enough to fuse protons (hydrogen nuclei) to helium nuclei



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- 0.001 sec to about 3 minutes after the Big Bang
- Fusion ends because density drops : about 25% helium, traces of Lithium, deuterium
- Amounts seen throughout the universe today (with slight enhancements of heavy elements via fusion in stars)

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Next Two Classes

- The Rest of History
- More on Inflation
- Did the Big Bang Really Happen?

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