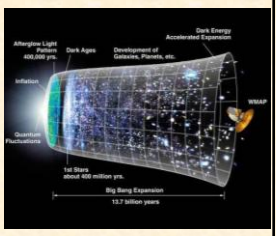
ASTR 1020: Stars & Galaxies

December 4, 2013

- Reading: Chapter 22, sections 22.2-22.3.
- *MasteringAstronomy* Homework on The Fate of the Universe is due on Dec. 6.
- SBO Extra Credit Observing session: Tonight at 7 pm.



Astronomy Picture of the Day

Stephan's Quintet (HST)

Last Lecture

- Chapter 23, Section 4: Dark Energy and the fate of the Universe.

Today

- Chapter 22: The Creation of the Universe

(the creation of all matter, light and energy).

Reading Clicker Question: During what time period do scientists suspect that all four forces of nature were unified?

A. within 10^{-43} seconds of the Big Bang
B. within the first millionth of a second
C. within the first second
D. within the first 10 hours
E. within the first 10 years

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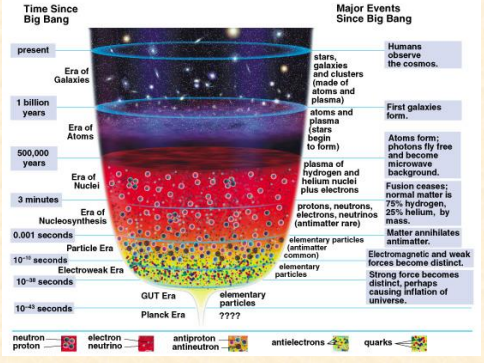
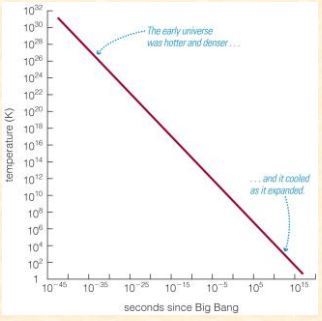
Chapter 23: In the VERY Beginning



Hot stuff!

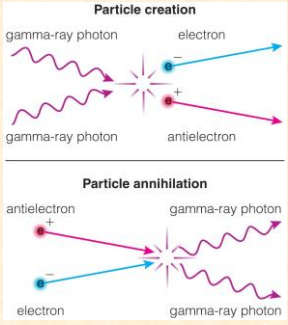
- Everything in the Universe was hotter at earlier times, and then cooled as it expanded
- The temperature at the earliest times was MUCH more than the energy we create in particle accelerators
- Cosmology at the earliest times is explored via particle physics!



Matter and Energy

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

Matter + antimatter ← → photons



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…

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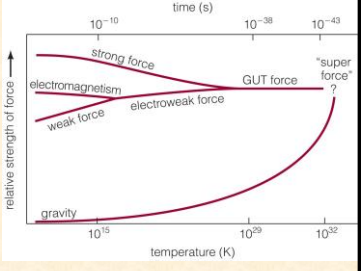
B. **Electromagnetism**
C. Strong Force
D. Weak Force

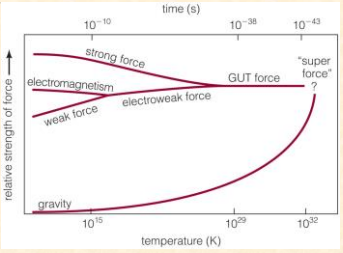
The Grand Unified Theory Era (GUT Era)

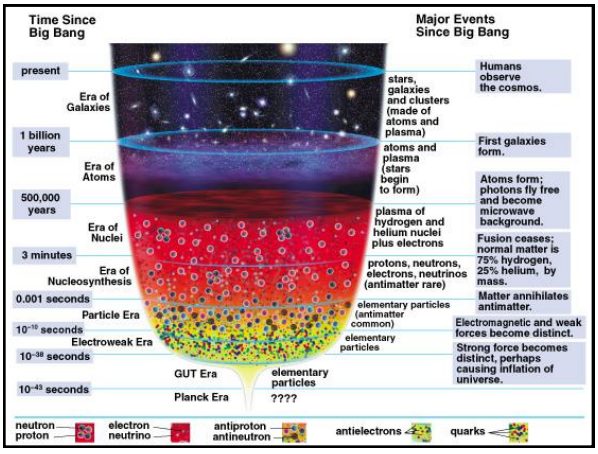
- Up to 10^{-38} sec
- Temperatures higher than can be created in particle accelerators
- Fundamental forces become distinct as the universe cools



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.





The Particle Era

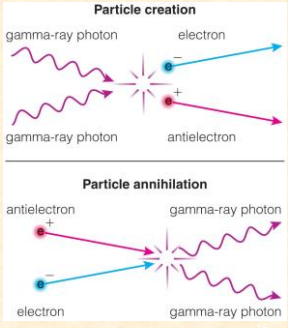
- Universe still hot: 10^{15} to 10^{12} K
- Particles now exist: electrons, protons; anti-protons, anti-electrons, neutrinos etc.
- Particle soup! Particles and photons/energy created and annihilated

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 is the difference between an electron and an anti-electron?

A. its charge
B. its mass
C. its spin
D. A and B
E. A and C

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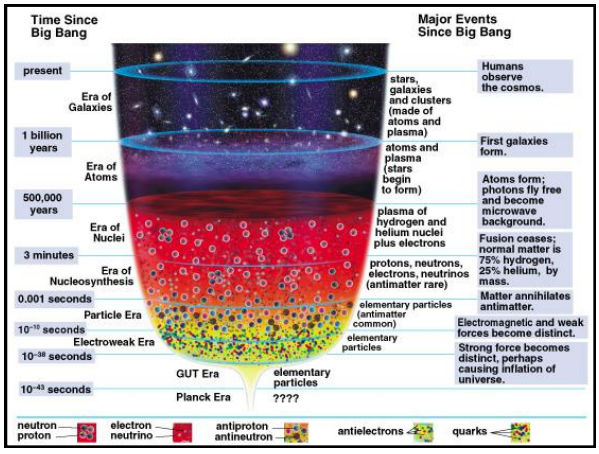
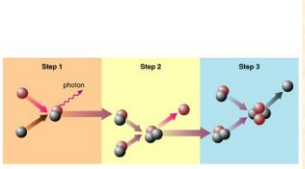


Era of Nucleosynthesis (fusion)

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



Era of Nucleosynthesis (fusion)

- 0.001 sec to about 3 minutes after the Big Bang
- Fusion ends because density drops : result is about 75% hydrogen, 25% helium, traces of Lithium, deuterium
- Amounts seen throughout the Universe today (with slight enhancements of heavy elements via fusion in stars)

Next Two Classes

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