Astronomy 122

This Class (Lecture 27):

Dark Matter & Dark Energy
ICES Form!!!

HW11 due Friday

Next Class:

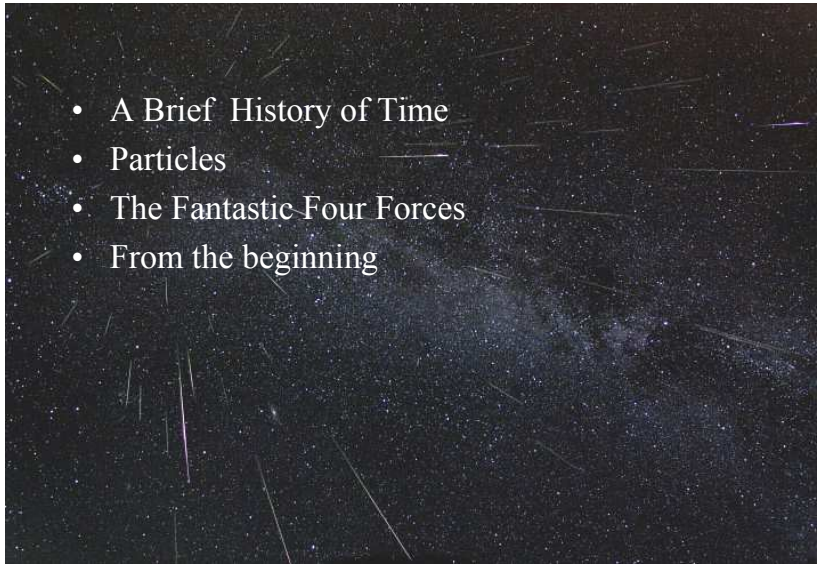
The End

Music: *The Universe Song* – Animaniacs

Final

- In this room at 1:30pm-4:30pm on May 5th.
- Designed to be 2 hours long.
- Half is just like the midterm on the new material.
- Half is review of the entire semester.
- You may bring a single sheet of paper with notes.
- Total exam will have 210 points, but graded out of 200 points.

Outline



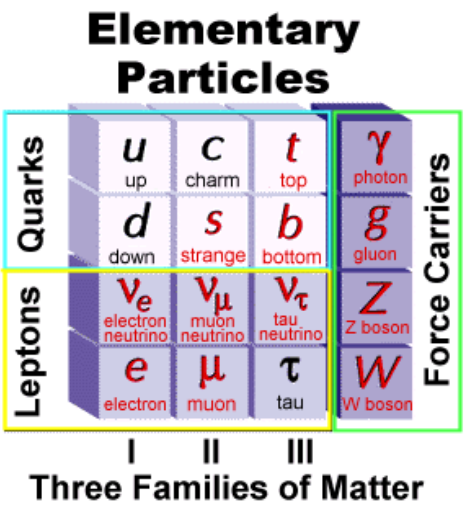
A Brief History of Time

A Little Background Info

To understand the early Universe, we need to talk about a few topics first:

1. Basic Particles
2. Matter and Anti-matter
3. The Four Forces of Nature

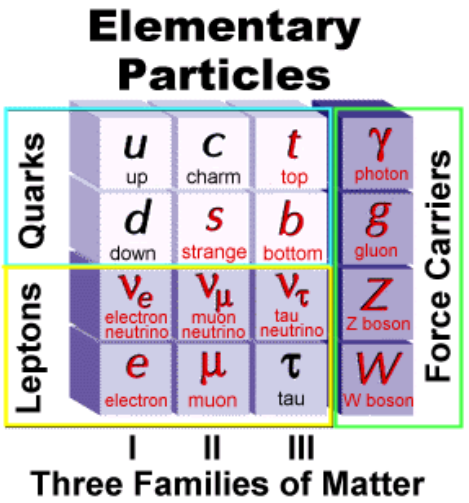
Basic Particles



http://sol.sci.uop.edu/~jfalward/elementaryparticles/elementaryparticles.html

Basic Particles

- There are three types of basic particles in nature
- **Quarks** - matter
  - Building blocks of protons and neutrons
- **Leptons** - matter
  - Electrons and neutrinos
- **Force Carriers** - energy
  - Photons, gluons, gravitons?



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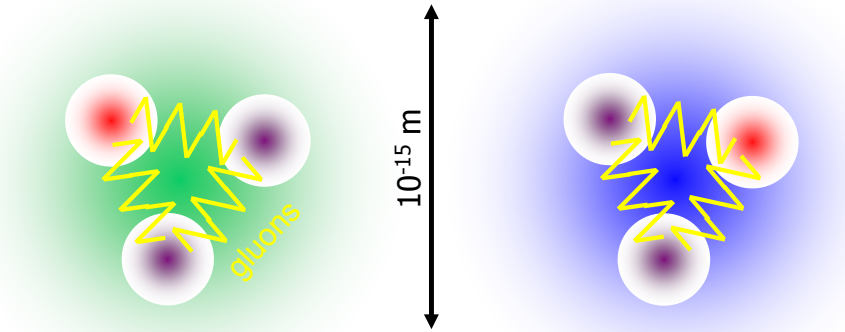
Quarks

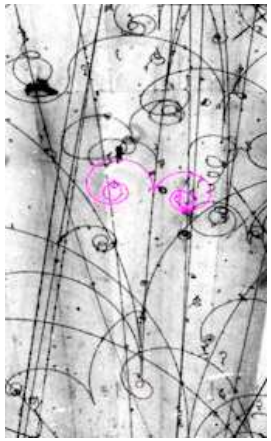
- The basic particles that make up protons and neutrons (held together by "gluons")



Proton (charge +1) =
2 "up" quarks (+4/3) +
1 "down" quark (-1/3)

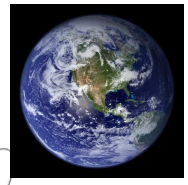
Neutron (charge 0) =
1 "up" quark (+2/3) +
2 "down" quarks (-2/3)

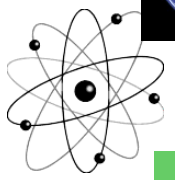
Matter & Anti-Matter

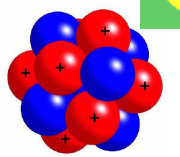


- Partner for each type of matter particle
  - Anti-electron=positron, anti-quarks, anti-neutrinos
- Anti-matter is stable by itself
  - Can have anti-protons, anti-atoms, anti-rocks, anti-people, anti-stars, anti-galaxies
- But when matter & anti-matter partners combine
  - **Annihilation** – matter converted to energy – $E=mc^2$
  - Example: paperclip + anti-paperclip annihilation – Energy release equal to a small nuclear bomb!

The Fantastic Four

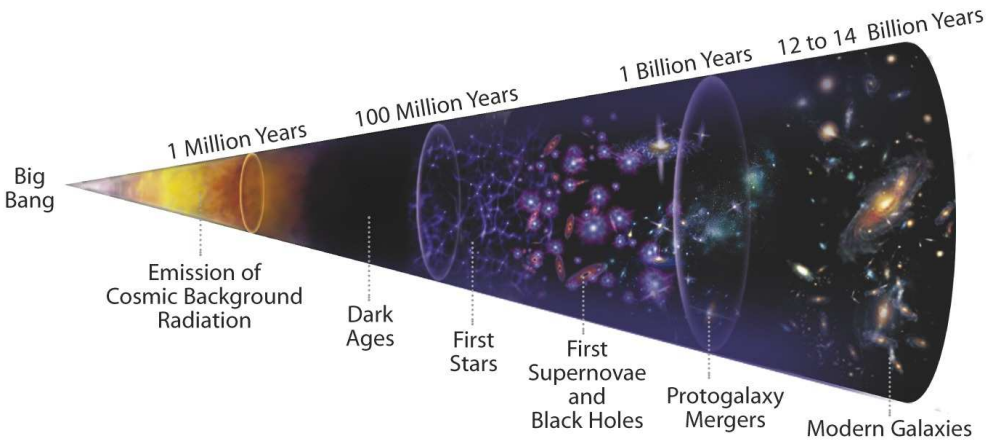






- **Gravity** - dominates large-scale action
- **Electromagnetism** - dominates chemical and magnetic interactions
- **Nuclear Weak** - controls nuclear reactions
- **Nuclear Strong** - binds atomic nuclei together

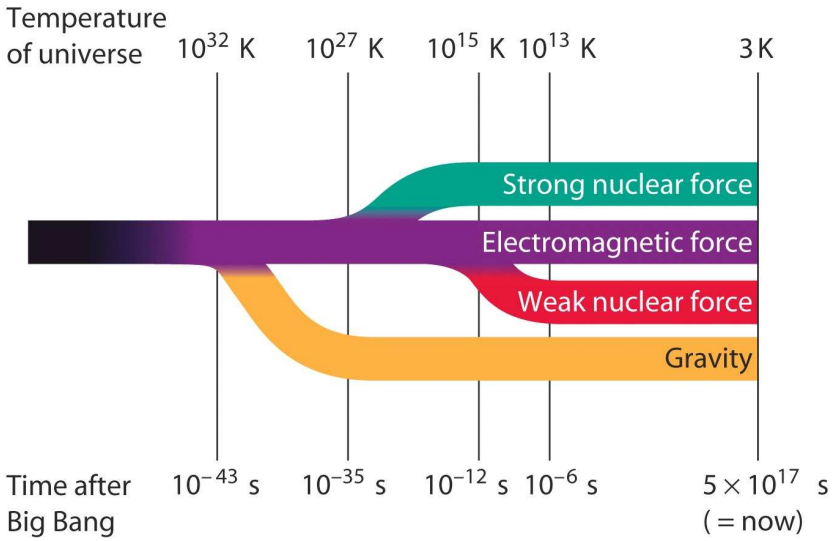
A Brief History of Time



The First Instant (to 10^{-43} sec)

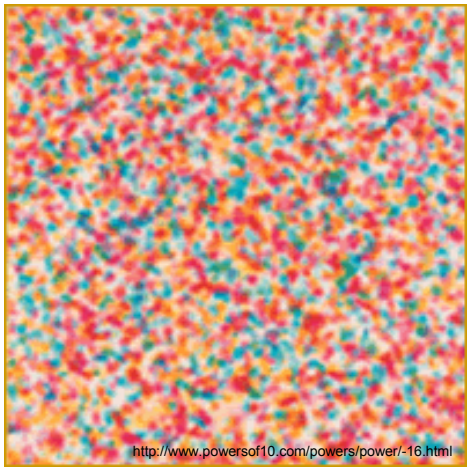
- Incredibly hot (more that 10^{32} K)
- Our current hypothesis – only one force in nature
  - The four forces were unified
  - Remains to be proven, as the theories we use to describe nature don't work in this era
- At the end of this era, gravity became a separate force
- Want a Nobel Prize? Develop a theory to describe this era of the Universe!

Dis-Unification of the Forces



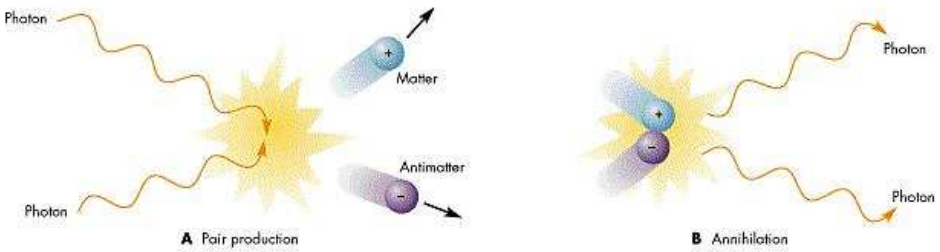
The GUT Era (until 10^{-35} sec)

- GUT = "Grand Unified Theory"
- Two forces
  - Gravity
  - Strong/weak/electro-magnetic
- Sea of free quarks (and anti-quarks) + photons + other basic particles
- Random fluctuations in density



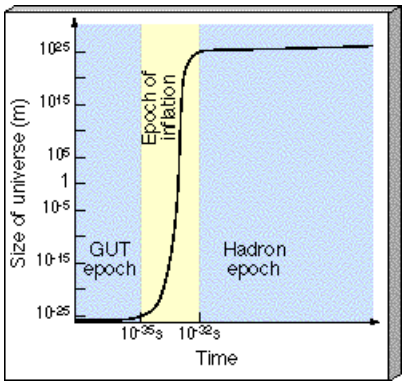
Matter and Anti-Matter

- In the early Universe, the photons were so energetic that photons could convert into matter/anti-matter pairs
- The particles created would soon annihilate and convert back to energy



Inflation (10^{-35} to 10^{-32} sec)

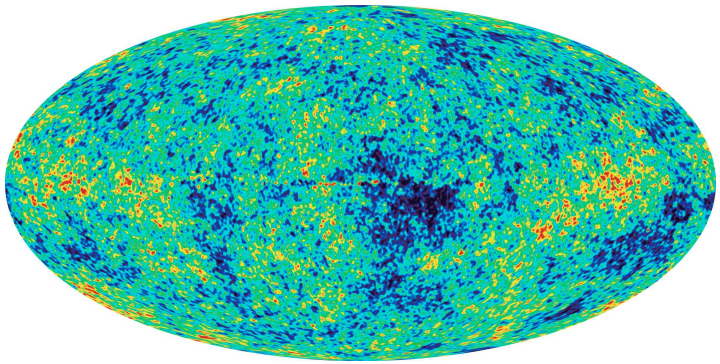
- Idea: Universe went through a period of extremely rapid expansion
- Expansion by more than a factor of $\mathbf{10^{50}}$!!
- Expansion driven by the splitting of strong and electro-magnetic/weak forces



- Areas that were close before inflation were now separated by millions of parsecs!

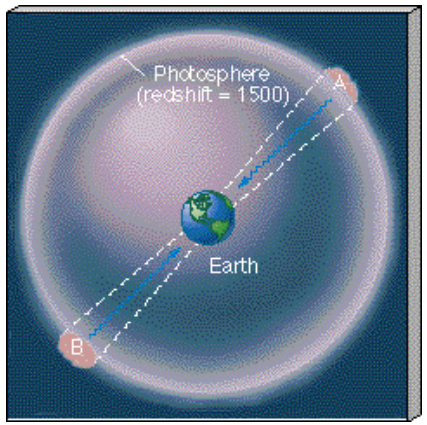
Small Scale Variations - Cosmological

Cosmological variations are less than 1 part in 100,000!



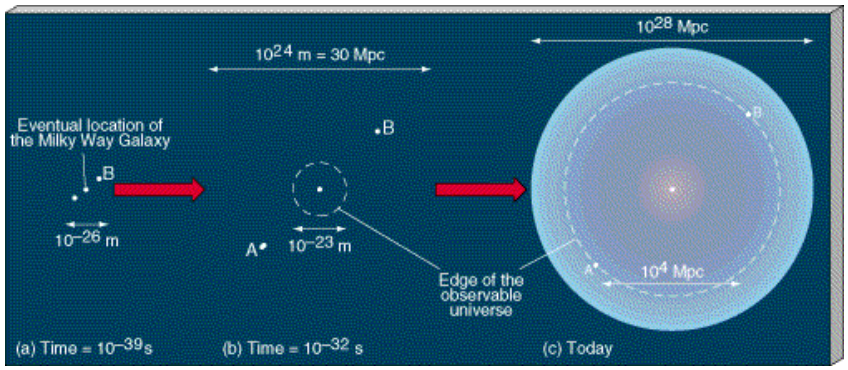
The Isotropy Problem

- The CMB looks very much the same all over the sky
- Thus, regions A and B were very similar to each other when the radiation we observe left them
- But there has not been enough time since the Big Bang for them ever to have interacted physically with one another
- Why then should they look the same?



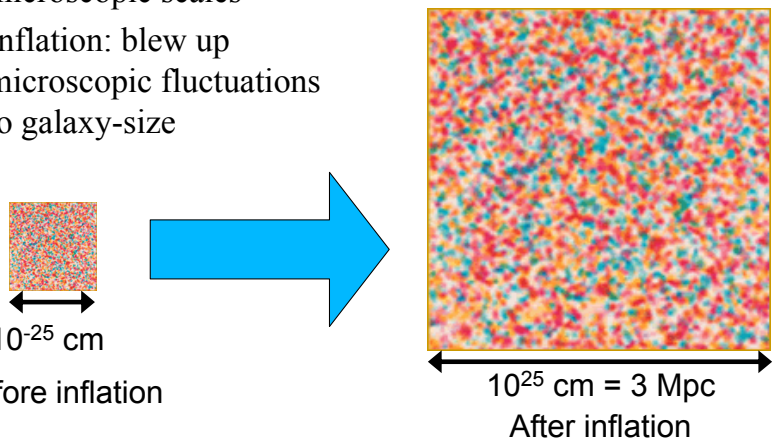
Inflation Solves the Isotropy Problem!

Regions that were close enough to interact in the early Universe were separated by inflation!



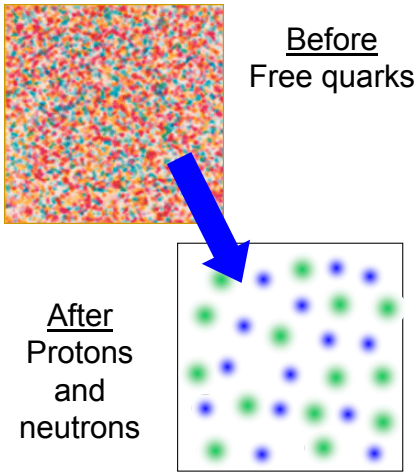
Origin of the CMB Fluctuations

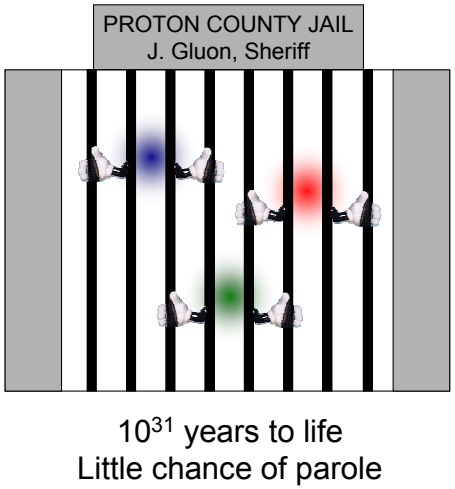
- Early Universe: a sea of particles & energy
- Density was constantly fluctuating on microscopic scales
- Inflation: blew up microscopic fluctuations to galaxy-size



Confinement of the Quarks

- 10^{-6} seconds: free quarks condensed into protons and neutrons





10^{31} years to life
Little chance of parole

The Universe is Made of Matter

- You, and I, and the Earth are all made of matter not anti-matter
- The Moon is made of matter, not anti-matter
- Local "neighborhood" in Milky Way is matter, gas between the stars
- The Universe is made of matter
- How did this come to be?

The Early Universe and Antimatter

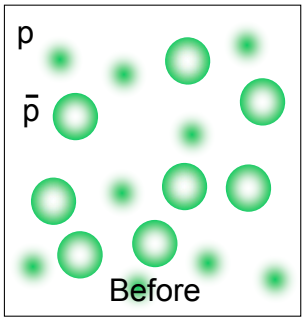
Strong evidence says:
The early universe had both matter and antimatter, but

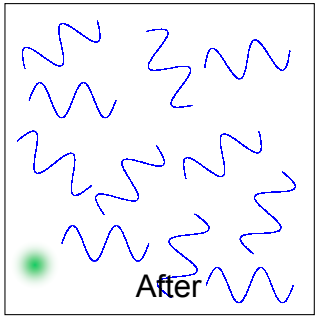
- For every 1,000,000,000 antimatter particles,
- There were 1,000,000,001 matter particles

Then annihilation happened, only the matter excess remained.

Annihilation of the Anti-matter

- 10^{-4} seconds:
  - Temperature dropped below the level at which photons have enough energy to create proton-anti-proton pairs
  - Remaining pairs annihilated → radiation
  - 1 proton in 10^{9} had no partner! That's us





The Early Universe and Antimatter

How did the matter excess get there?
Most likely guess:

- The Universe began with equal amounts of matter & antimatter.
- But very high energy reactions slightly favored matter.
- Fermilab experiments: such reactions are possible!
- Stay tuned!

Example of inner space--outer space, particle--cosmology connection.

The End of the First Second