# Astronomy 122

This Class (Lecture 26):

The Primeval Fireball

***HW10 due Friday***

Next Class:

Dark Matter & Dark Energy
ICES Form!!!



# Outline

- Hubble's Law → implications
- An expanding Universe!
  - Run in movie in reverse ⇒ The Big Bang
- The Cosmic Microwave Background (CMB)
- A Brief History of Time



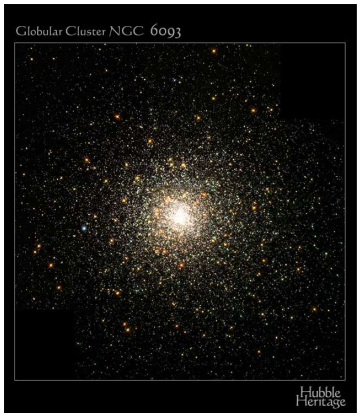
# The Hubble Law and The Age of the Universe

- We can use the Hubble Law to estimate the age of the Universe
- Imagine watching a movie of the expansion of the Universe
  - Now, run the movie backwards!
  - Expansion becomes contraction
- If we assume the Universe has been expanding at a constant rate…
  - *time = distance/velocity*
- Recall, $v=H_o d$…
  - Time = $1/H_o$=1/72 km/s/Mpc = **14 billion years**



# The Age of the Universe

- Other methods to date the Universe…
- Globular clusters
  - oldest stars
  - about 13 billion years old
- Current best estimate from the WMAP satellite
  - 13.7 billion years old



# Group Activity

How old would the Universe be if the Hubble constant were equal to your age (in km/s/Mpc)?



# Putting it all together:

1. The Universe is expanding
2. Earlier Universe was more dense
3. Earlier Universe was hotter.

The origin of the Universe can be described by the idea of the Big Bang.



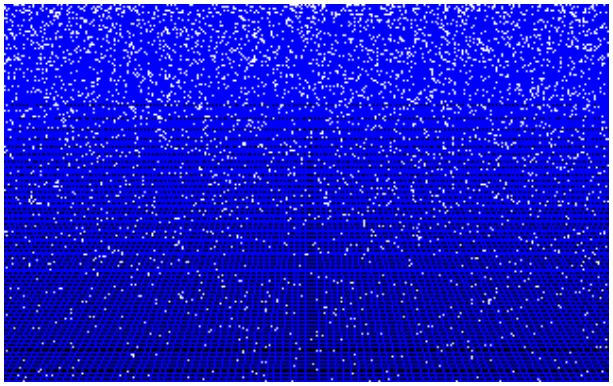
# The Biggest Bang since the Big One

- Occurred everywhere at once
- The Universe was suddenly filled with energy – hot and dense
- The **beginning** of spacetime, matter, and energy
- As spacetime expanded, the Universe became less dense and cooler
- Eventually forming the stars and galaxies we see today



# The Big Bang

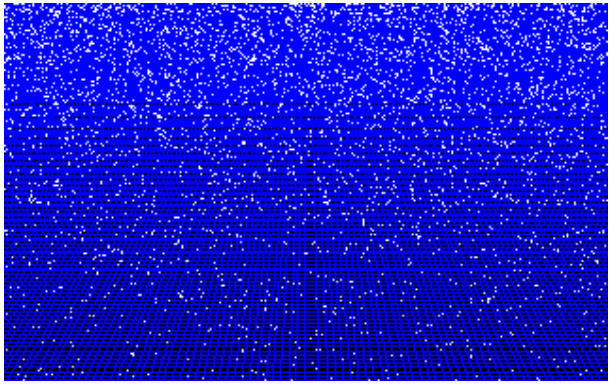
- No special points or locals
- Expansion of **all** space
- **Not** an explosion into empty space.



http://www.anzwers.org/free/universe/bigbang.html

# The Big Bang

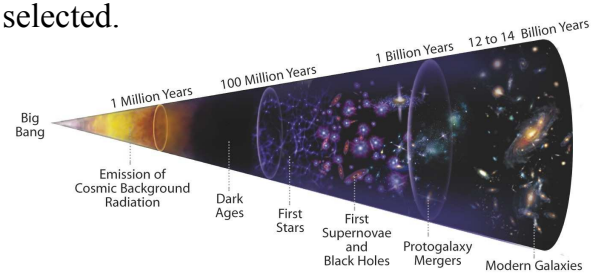
- Big Bang has no center
- Happened everywhere
- Wherever you go, there was the big bang
- So as we talk about the very dense early universe, remember that we are talking about what happened not just far away at the edge of the Universe, but **right here!** ...smooshed up small, but still **right here!**





# The Big Bang

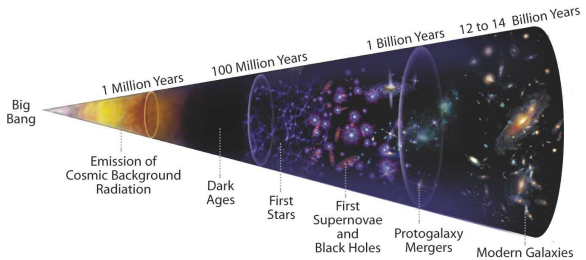
- In the 1940s, extrapolating on Hubble's Law, George Gamow proposed the the universe began in a colossal "explosion" of expansion.
- In the 1950s, the term BIG BANG was coined by an unconvinced Sir Fred Hoyle who tried to ridicule it.
- In the 1990s, there was an international competition to rename the BIG BANG with a more appropriate name, but no new name was selected.






# The Big Bang

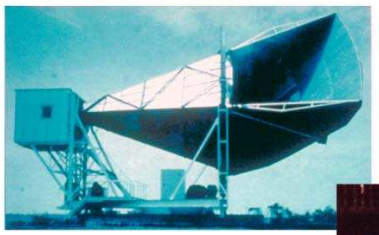
- Scientists do not have a definitive explanation for the Big Bang
- But, a growing body of observations supports the theory that the event did occur.



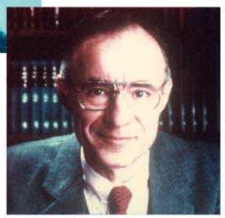



# The Early Universe was HOT!

- If the early Universe was so hot, we should be able to see it glowing. Right?
- **Yep, we do!** But, as the Universe expanded, it redshifted down to the microwave.
- Now, it is called the Cosmic Microwave Background (CMB).
- First detected by Robert Wilson and Arno Penzias.

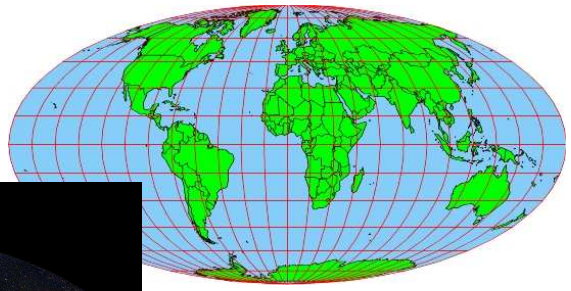

Microwave Receiver

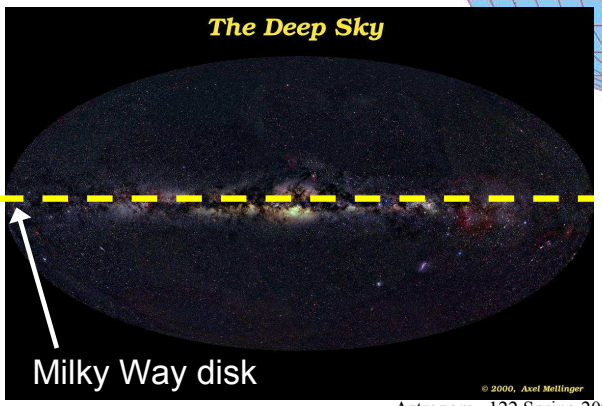

Robert Wilson


Arno Penzias

MAP990045

# How to Understand Sky Maps

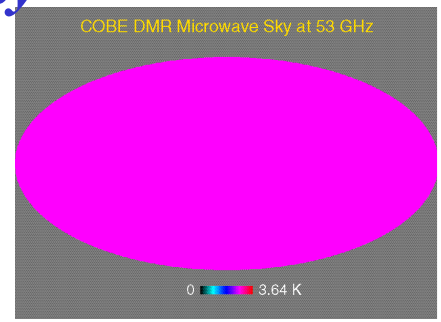




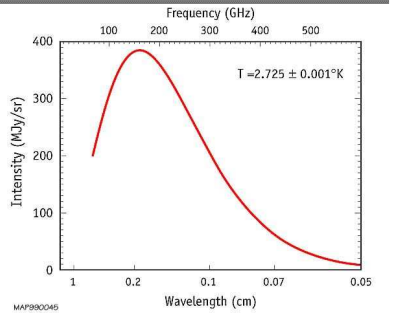



# In Fact, a Rather Uniform Blackbody

- All over the sky, we see blackbody radiation
  - Temperature = 2.73 K
- Provides compelling evidence for the Big Bang Theory
- Almost perfectly *isotropic*
  - Nearly the same in every direction
- Indicates that, over large scales, the Universe is uniformly spread out



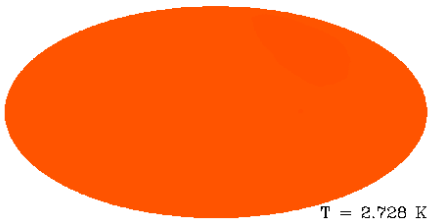

Cosmic Background Explorer (COBE) satellite (launched 1989)






# Small Scale Variations

- There are small scale variations in the CMB.
- Largest variations are due to motions
  - Motions of the Sun around the Galaxy
  - Motions of the Galaxy in the Local Group
  - Motions of the Local Group in our supercluster

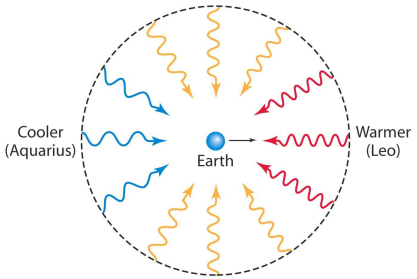


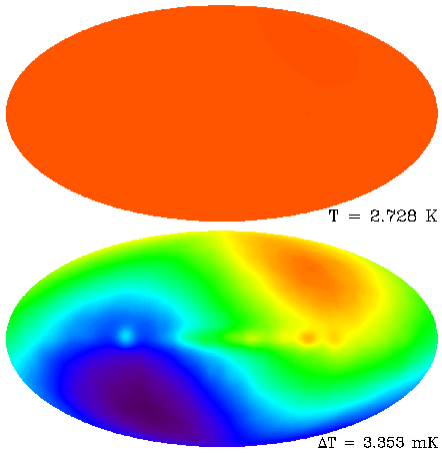

- There are also Galactic sources of microwave radiation
- First, we have to remove these variations…
  - What is left is cosmological - from the Big Bang

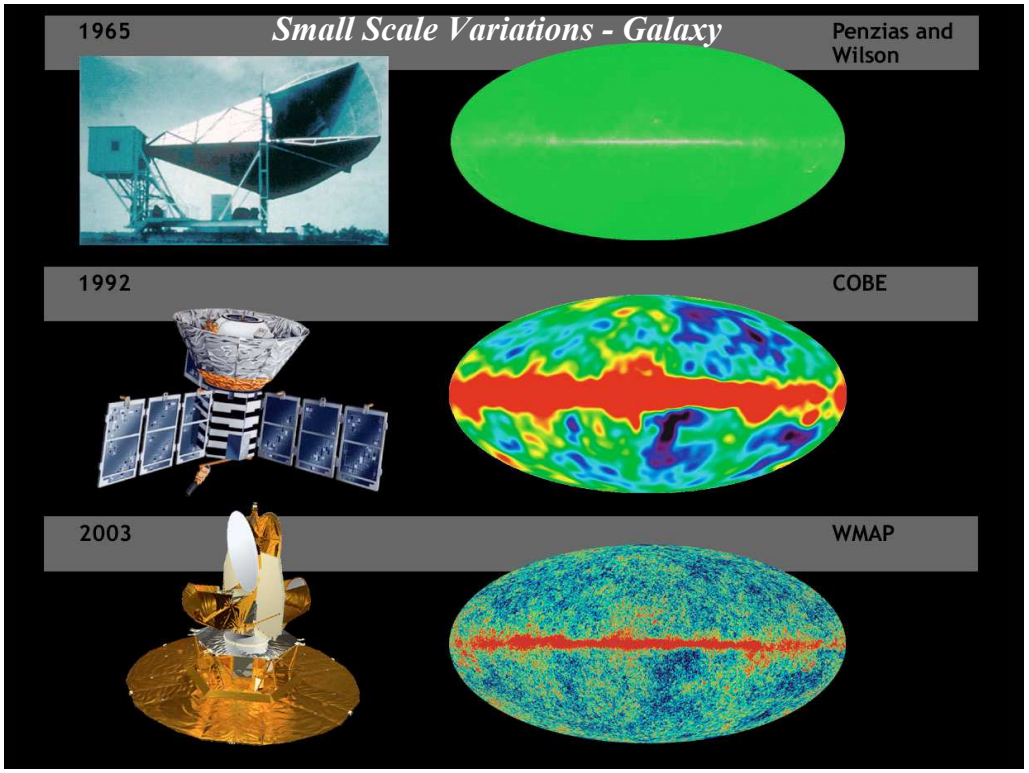


# Small Scale Variations - Motion

- Due to our movement with respect to the Universe
- We are moving about 600 km/s or 1.3 million mph

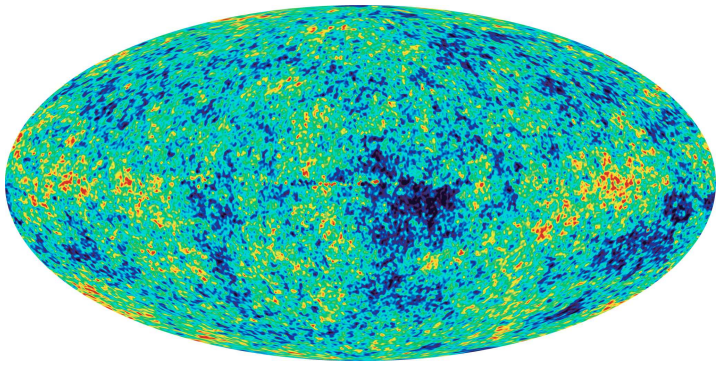





# Small Scale Variations - Cosmological

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



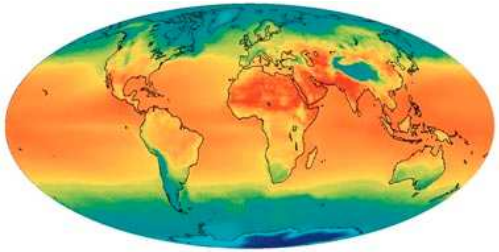


# Unknown Fluctuations…


Further refinements of the cosmic microwave background reveal a deeper meaning for physicists to ponder.

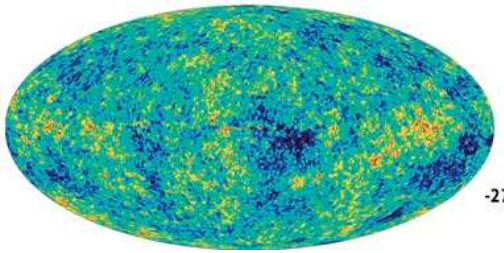


# WMAP took a "baby picture" of the Universe– only 400000 yrs old.



Earth Temperatures

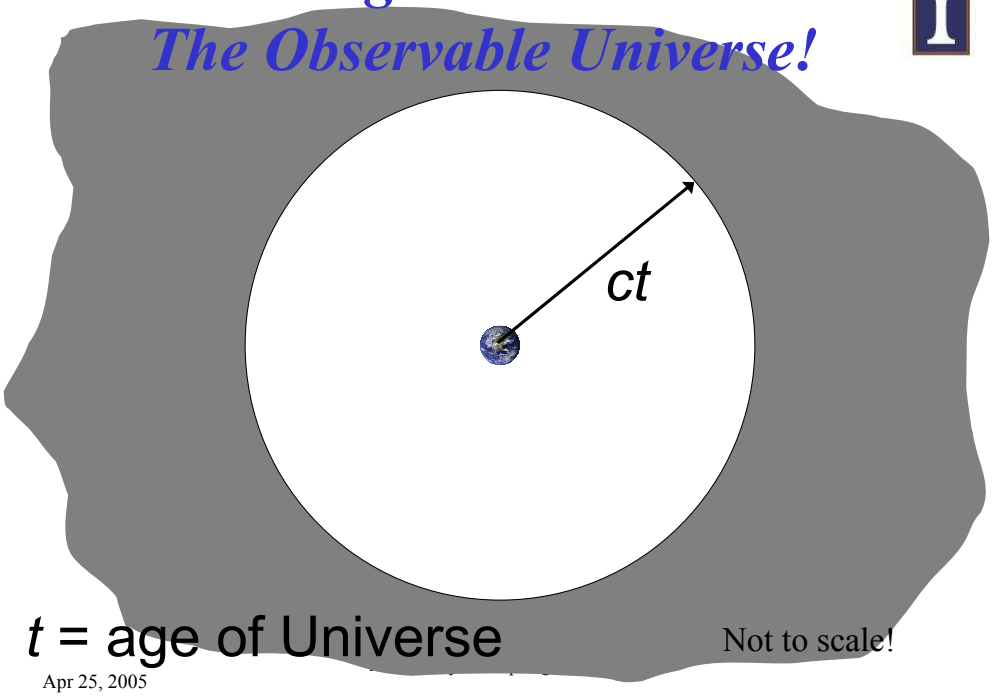
-63° -13° 37°
Centigrade
June 1992



Microwave Sky Temperatures

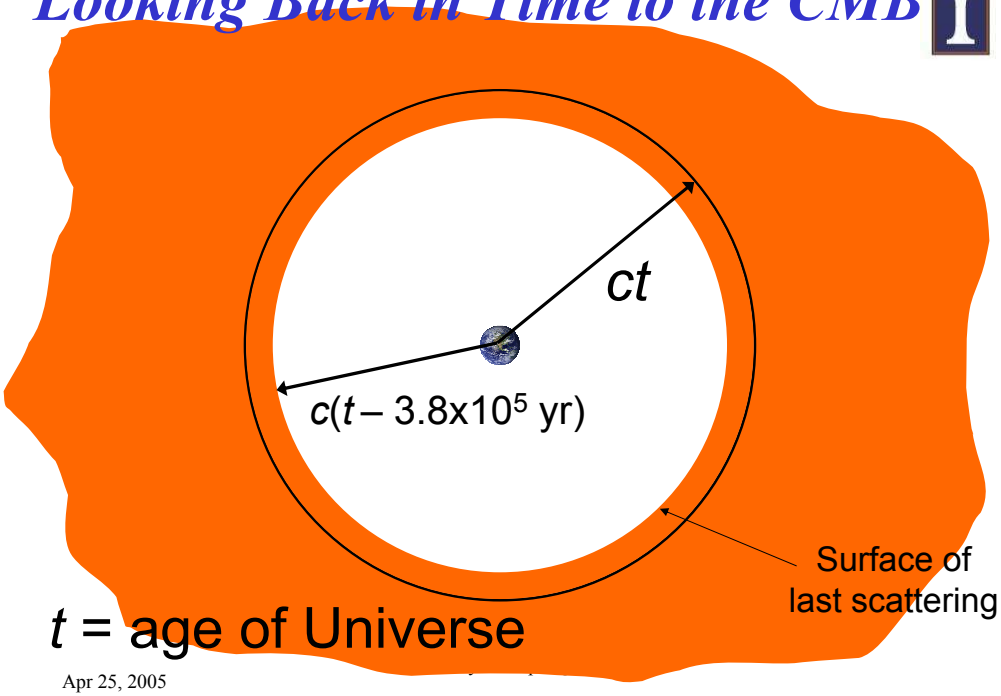
-270.4252° -270.4250° -270.4248°
Centigrade
380,000 Years after Big Bang

# Looking Back in Time: The Observable Universe!





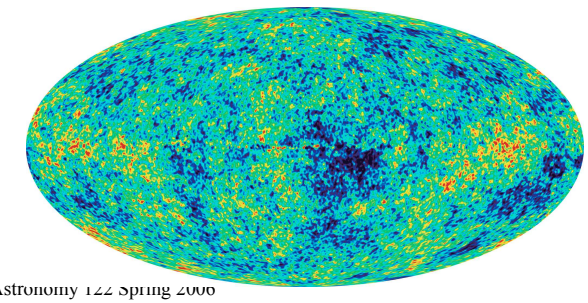

# Looking Back in Time to the CMB





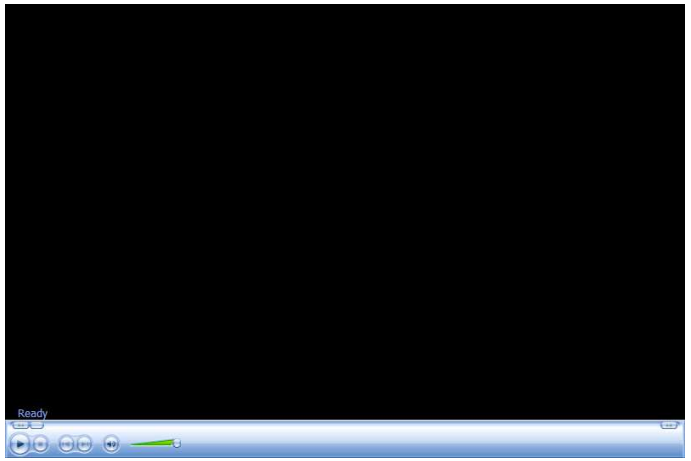

# The Seeds of Galaxies

These small perturbations in temperature are the fluctuations (smaller than 1 in a 1000) that caused the large scale structures we see today. This is what formed galaxies. All of this happened only 400,000 years after the Big Bang.



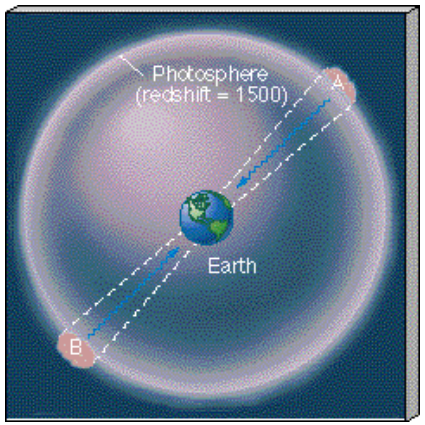


# Galaxy Structure



# 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?






# The Universe: Cliff Notes

- Began with a Big Bang
  - 13.7 billion years ago
- Still expanding and cooling
  - The rate of expansion is known
- It is BIG
  - As far as we are concerned, it is infinite in any direction
- The universe is homogeneous and isotropic
  - **Homogeneous** - The same "stuff" everywhere
  - **Isotropic** - The same in all directions
- Our place in the Universe is not special
  - Extension of the Copernican revolution
- The center of the Universe is everywhere or nowhere!



# THE VERY EARLY UNIVERSE

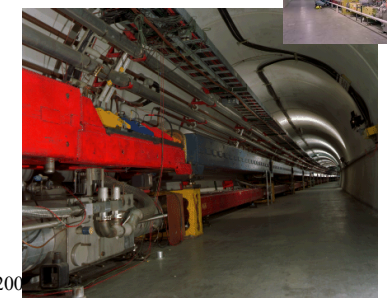
Since Big Bang works well so far, we have confidence to think about very early times:

t << 1 sec !

- Temperature and energies are ***ultrahigh***

***Q***: How to probe such high energies?
Hint: it's in the Great State of Illinois

**Fermilab**





# INNER SPACE / OUTER SPACE

*Fermilab is a telescope!*

Probes conditions in Universe at $10^{-12}$ s

**Universe was $10^{12}$ K hot!**

…but also…

*"The Universe is the poor man's accelerator"*

Probes conditions inaccessible at laboratories

# A Brief History of Time



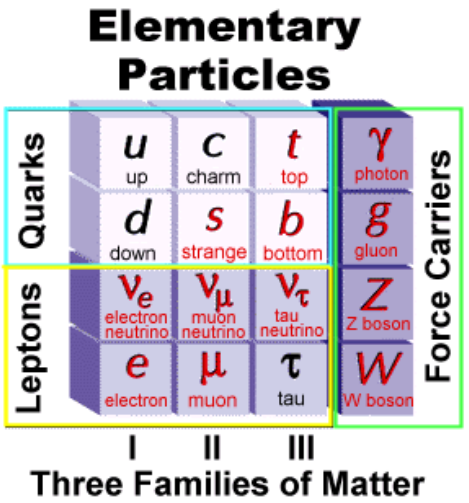
# A Little Background Info

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

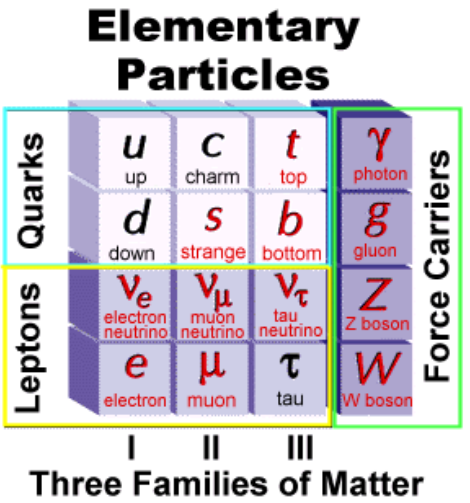




http://sol.sci.uop.edu/~jfalward/elementaryparticles/elementaryparticles.html



# 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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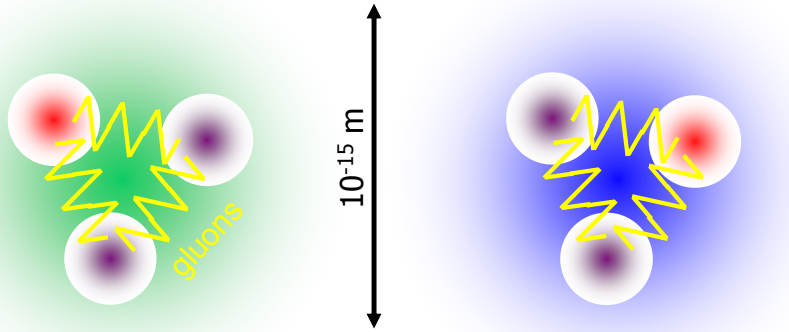
# Quarks

- 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)



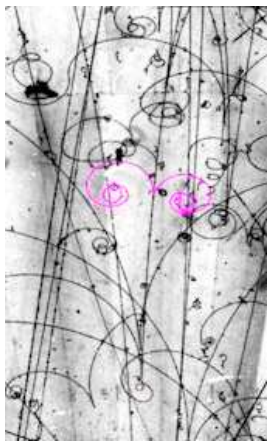
# The Universe is Made of Matter

- 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?



# Matter & Anti-Matter

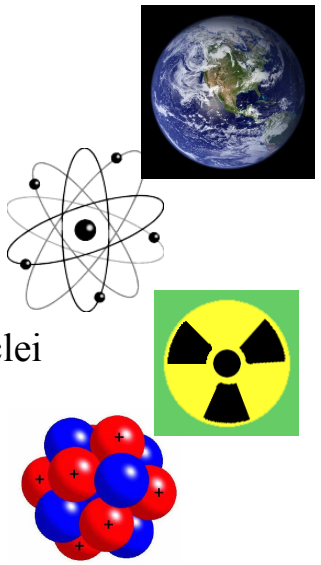
- Partner for each type of matter particle
  - Anti-electron=positron, anti-quarks, anti-neutrinos
- Anti-matter is stable by itself
  - Can have anti-protons, anti-atoms, anti-rocks, anti-people, anti-stars, anti-galaxies
- But when matter & anti-matter partners combine
  - **Annihilation** – matter 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*