Astronomy 330

TR 1000-1050
Noyes Laboratory 217

This class (Lecture 4):

The CMB

Next Class:

Origin of Elements

Presentation Synopsis due Tuesday!
(grace period until Feb 3rd)

Music: *The Universe is You* – Sophie Ellis-Bextor

You need to Register You Clicker

- Go to link on syllabus to register your clicker.
- **Bring it to class every day.**

Outline

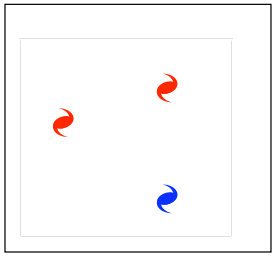
- An expanding Universe, implications
- The early Universe– The origin of H

Living in an Expanding Universe

Consider a large "box" containing many galaxies

- Total mass in box today: M_{today}
- Total volume in box today: V_{today}
- ***Density today*** $= M_{today} / V_{today}$

The Universe box



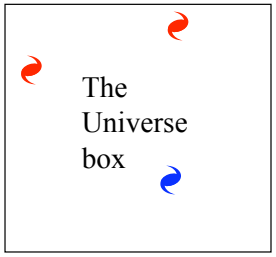
Tomorrow

How does the density of the Universe change with time?

Living in an Expanding Universe

How does the density of the Universe change with time?
As the Universe expands:

- $M_{tomorrow}$ stays the same
- $V_{tomorrow}$ becomes larger
- Density $M_{tomorrow}/V_{tomorrow} \Rightarrow$ *smaller*



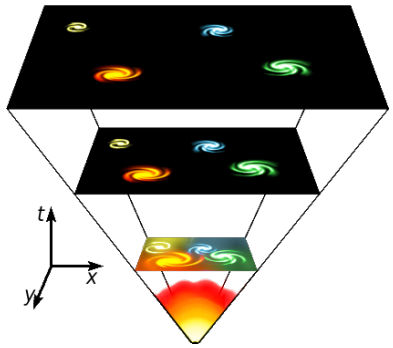
$M_{tomorrow}/V_{tomorrow} < M_{today}/V_{today}$

Density changes with time!

- Universe was denser in the past
- Universe will be less dense in the future

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. Where did the Big Bang happen? The Universe is homogenous & isotropic.

The Biggest Bang since the Big One

- Occurred everywhere at once
- Not an explosion into empty space.
- The Universe was suddenly filled with energy – hot and dense
- The **beginning** of spacetime, matter, and energy

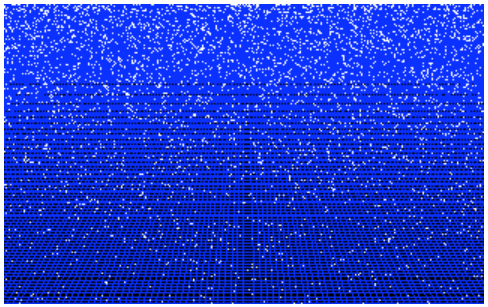
Question

Which of the following is an incorrect statement about the Universe.

a) It is expanding.
b) It started out very dense and very hot.
c) It is less dense today than it was in the past.
d) It is cooler today than it was in the past.
e) It started out as an explosion into empty space.

The Big Bang

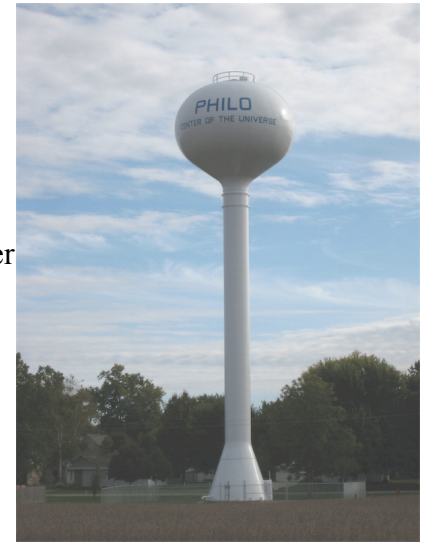
- No special points or locales
- Expansion of **all** space
- As spacetime expanded, the Universe became less dense and cooler
- Eventually forming the stars and galaxies we see today



http://www.atlasoftheuniverse.com/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!**

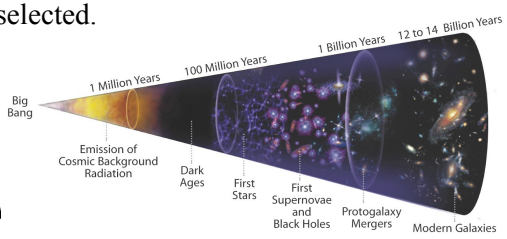


The 3rd Revolution

1. Copernicus and others: We are not the center of the solar system. The Earth is a typical planet.
2. Shapley and others: We are not the center of the Galaxy. The Sun is a typical star.
3. Hubble and others: We are not in the center of the Universe. The Milky Way is a typical galaxy.

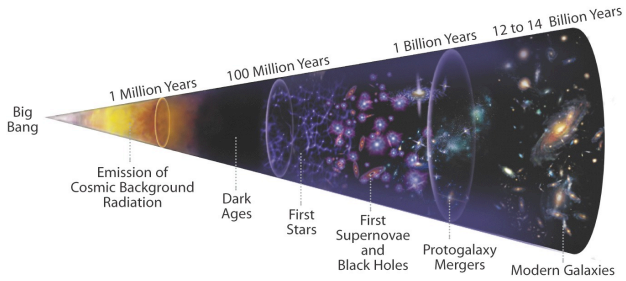
Naming the Big Bang

- 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.

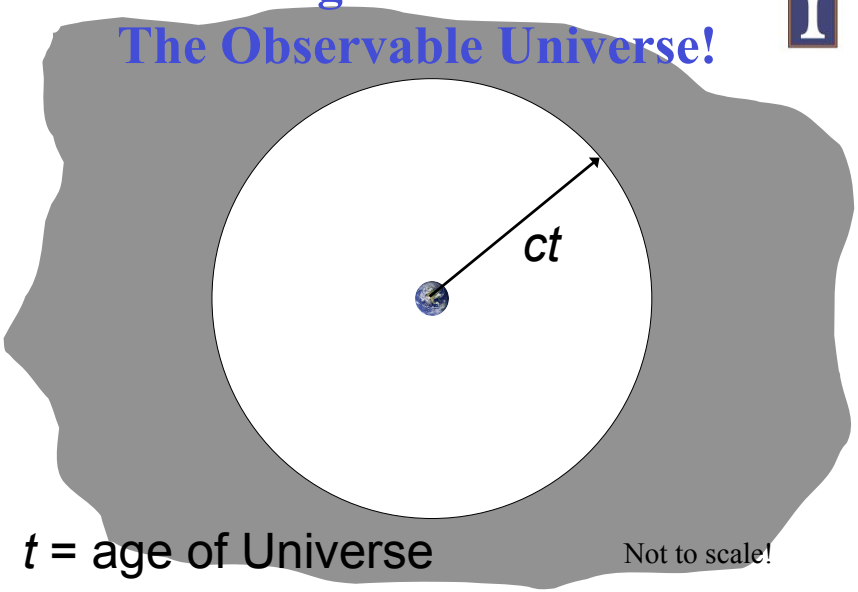


Question

Where did the Big Bang occur?

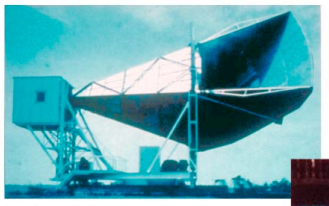
a) Everywhere.
b) At the edge of the Universe.
c) Just a little past the edge of the observable Universe.
d) Somewhere in the outer region of the Milky Way.
e) Snyder Hall, last Saturday night, 11:33 pm.

Looking Back in Time: The Observable Universe!

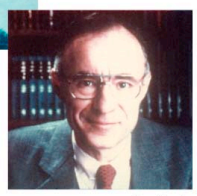


The Early Universe was *HOT*!

- 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.

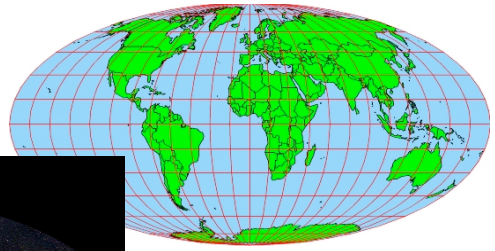

Microwave Receiver

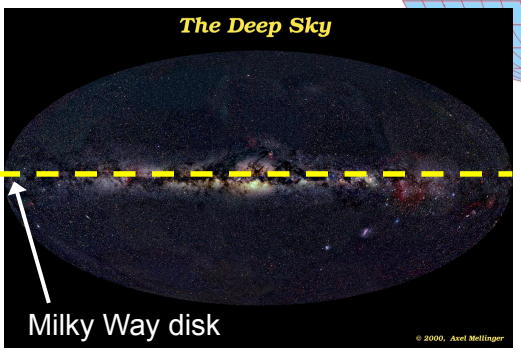

Robert Wilson


Arno Penzias

MAP990046

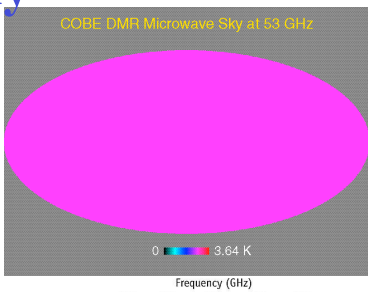
How to Understand Sky Maps

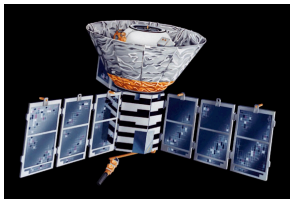




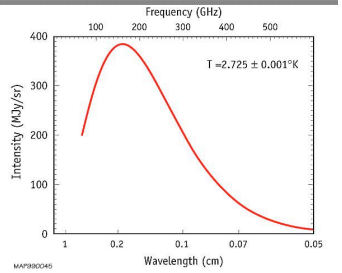
In Fact, a Rather Uniform Blackbody

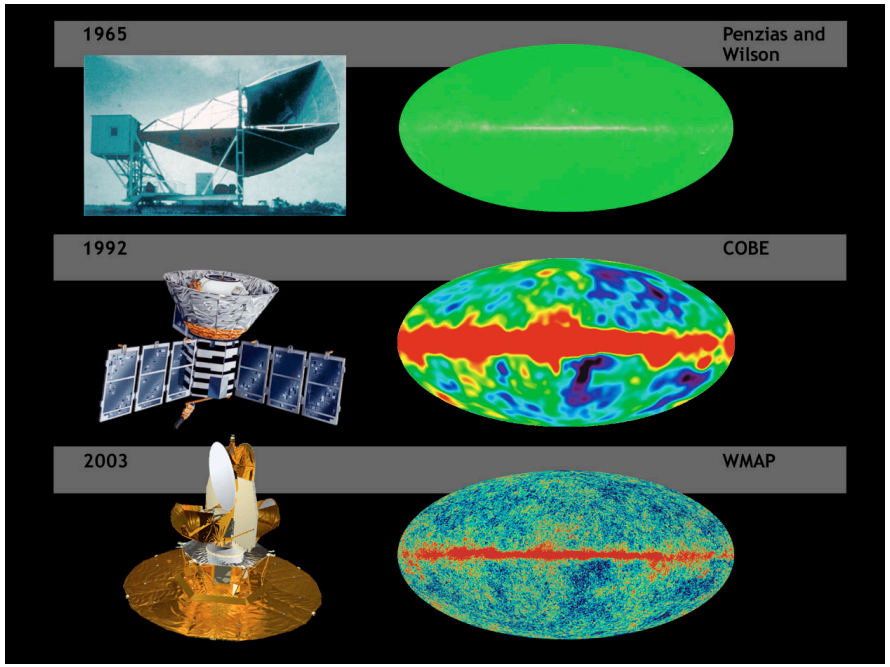
- All over the sky, we see blackbody radiation
  - Temperature = 2.73 K
- Provides compelling evidence for the Big Bang Theory
- Almost perfectly *isotropic*
  - Nearly the same in every direction
- Indicates that, over large scales, the Universe is uniformly spread out



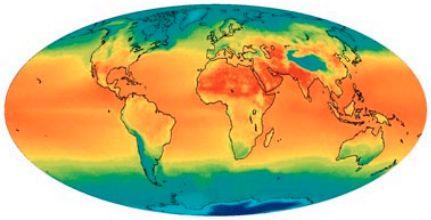


Cosmic Background Explorer (COBE) satellite (launched 1989)



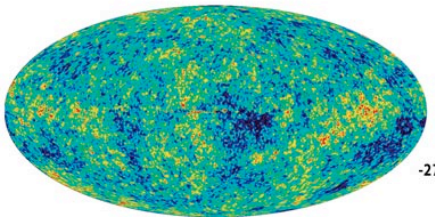


WMAP took a "baby picture" of the Universe– only 400000 yrs old.



Earth Temperatures

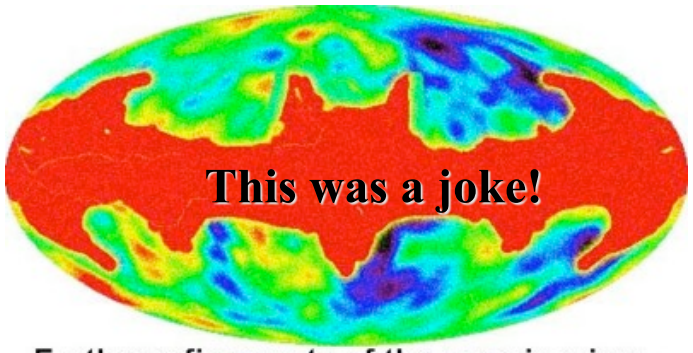
-63° -13° 37°
Centigrade
June 1992



Microwave Sky Temperatures

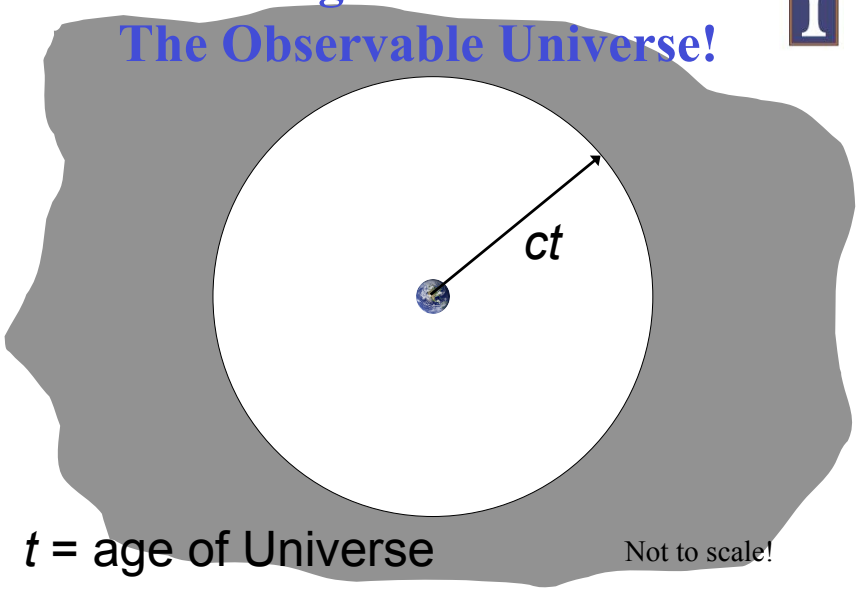
-270.4252° -270.4250° -270.4248°
Centigrade
380,000 Years after Big Bang

Unknown Fluctuations…

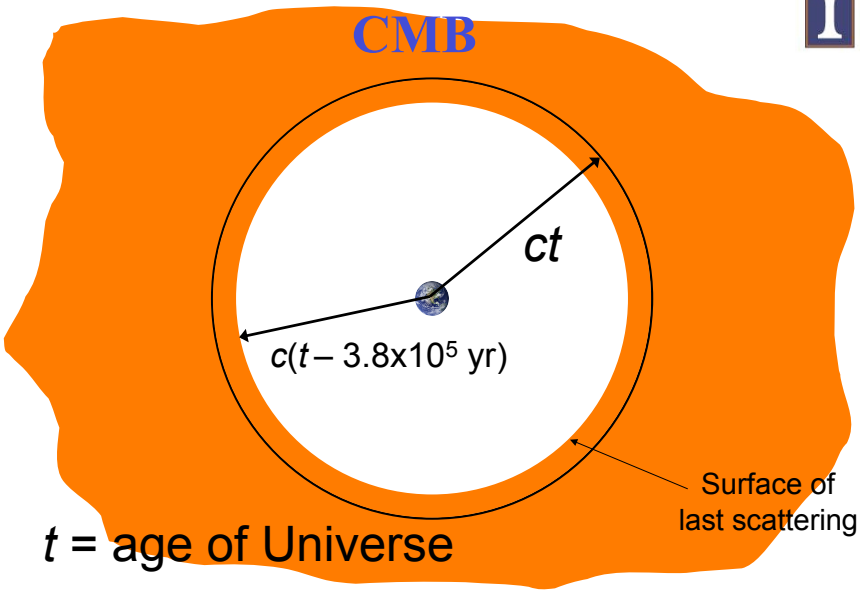


Further refinements of the cosmic microwave background reveal a deeper meaning for physicists to ponder.

Looking Back in Time: The Observable Universe!



Looking Back in Time to the CMB



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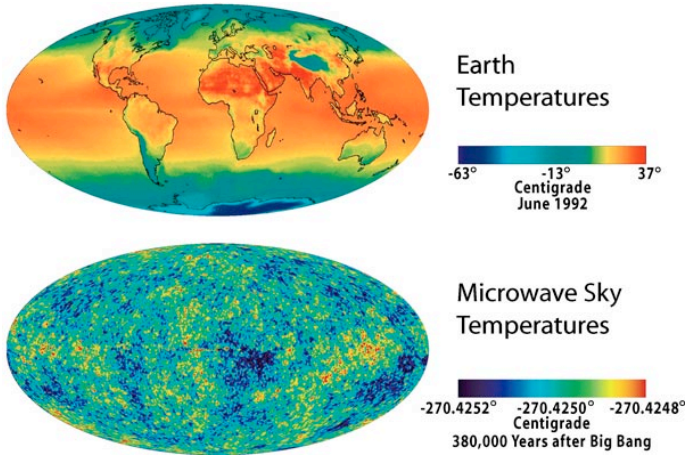
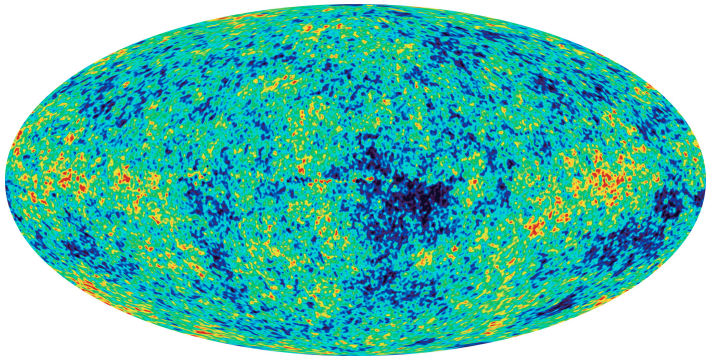


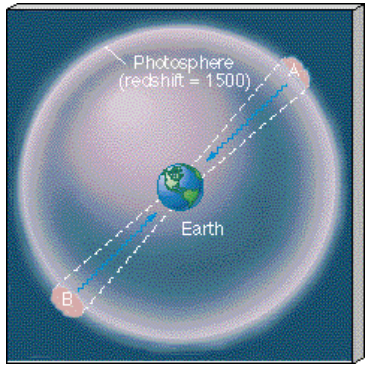
The Seeds of Galaxies

These small perturbations in temperature are the fluctuations (smaller than 1 in a 100,000) 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.

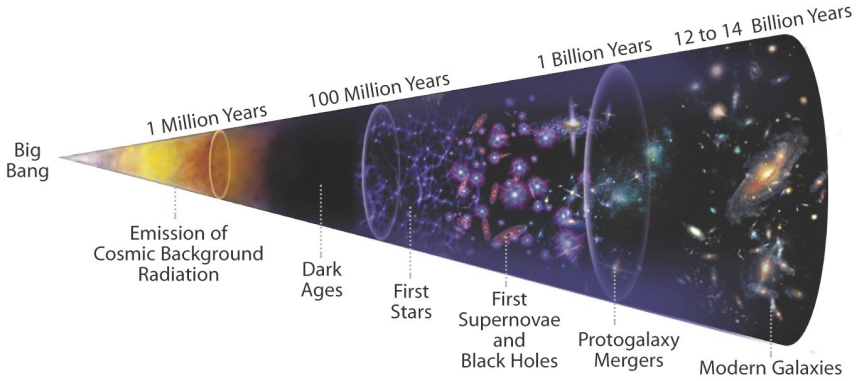


The Isotropy Problem

- 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 do they look the same?



A Brief History of Time



THE VERY EARLY UNIVERSE

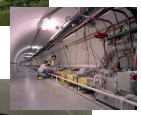
Since Big Bang works well so far, we have confidence to think about very early times:

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

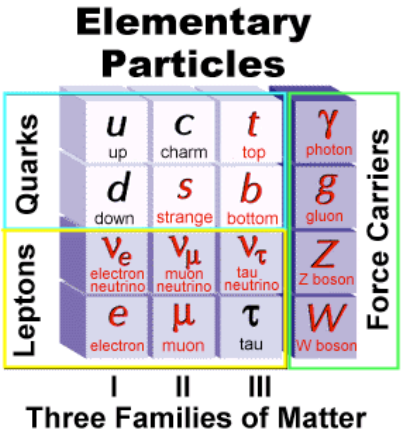
A Little Background Info

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

1. Basic Particles
2. Matter and Anti-matter

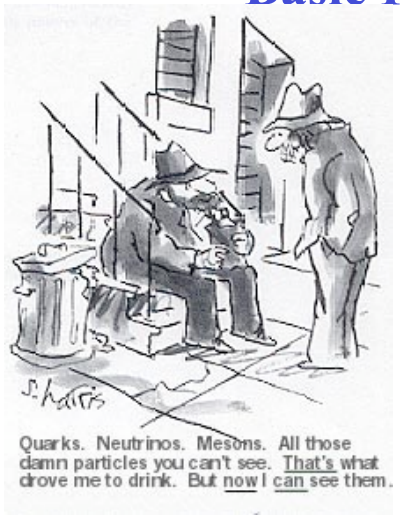
Basic Particles

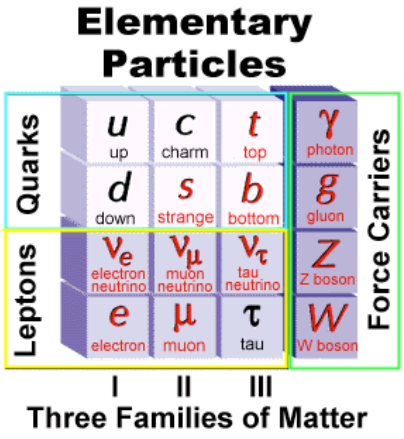
- There are three types of basic particles in nature
- **Quarks** - matter
  - Building blocks of protons and neutrons
- **Leptons** - matter
  - Electrons and neutrinos
- **Force Carriers** - energy
  - Photons, gluons, gravitons?



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

Basic Particles





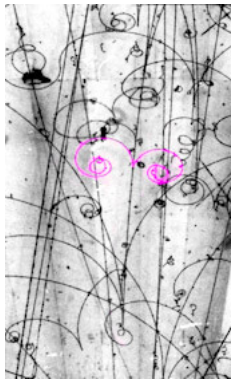
http://sol.sci.uop.edu/~jfalward/elementaryparticles/elementaryparticles.html

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



Matter & Anti-Matter

- 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!