Astronomy 330

This class (Lecture 4):

Cosmology and the Origin of Elements

Next Class:

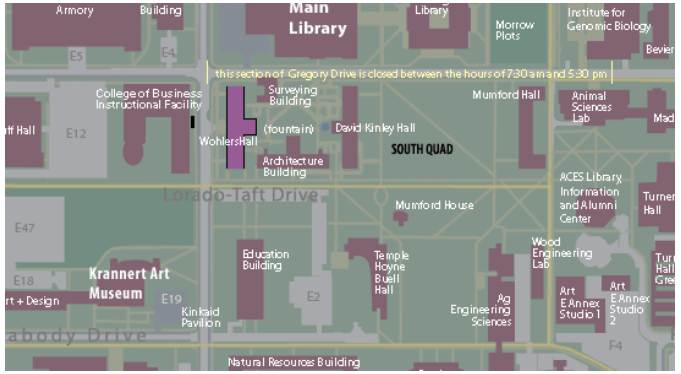
From Atoms to Molecules to Clouds

HW 1&2 due Sunday

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

Discussion Sections Moved

Davenport Hall discussion sections are now to be held at Wohler Hall room 138.



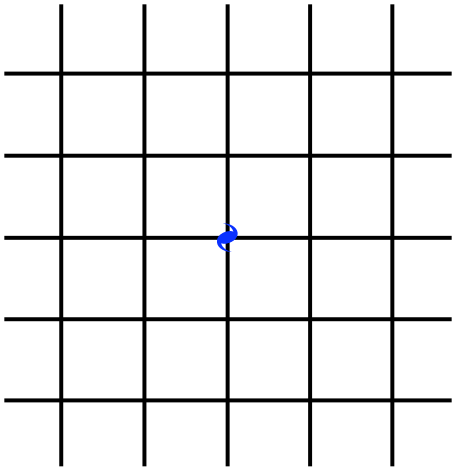
You need to Register You Clicker

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

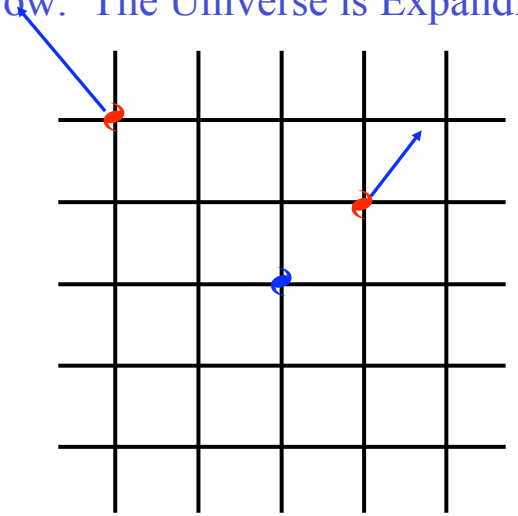
Outline

- The early Universe– The origin of H
- The probable fate of the Universe

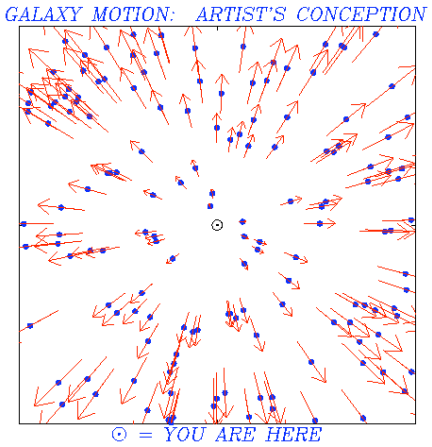
Dude, The Universe is Expanding.



Wow. The Universe is Expanding.



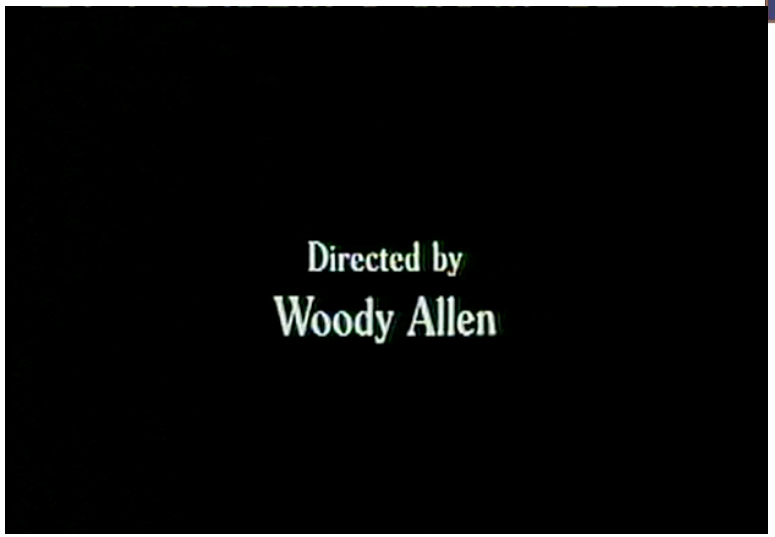
Gives the Impression of Being Special



Hold on a minute there!

- Why don't we expand with the Universe?
- Other forces hold us together
  - Atoms - nuclear forces
  - Molecules & living beings – electromagnetic forces
  - Planets, stars, and galaxies – gravity
- But gravity can't hold galaxy superclusters together
  - Expansion grows stronger with distance (more expanding space)
  - Gravity grows weaker with distance (inverse square law)
- **Brooklyn isn't expanding!**

Brooklyn



 Annie Hall (1977)

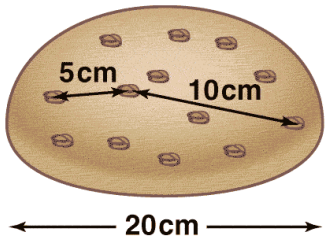
What do you think?

- The Universe is expanding, how do you feel about that?

http://www.calresco.org/ewp/confuse.htm

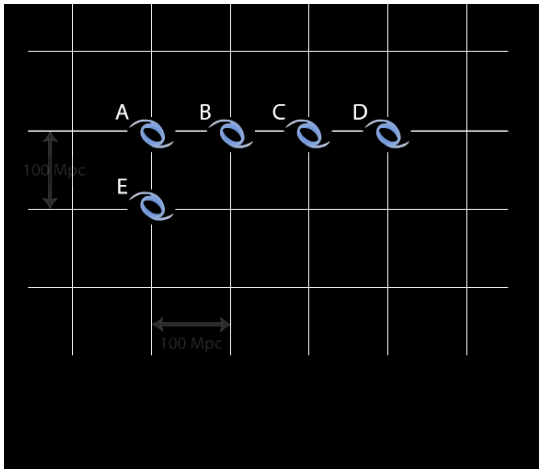
Analogy– Raisin Bread

The raisins are like galaxies.



Raisins stay the same size, like Brooklyn.

Another Expansion Graphic



Another Expansion Graphic

Question

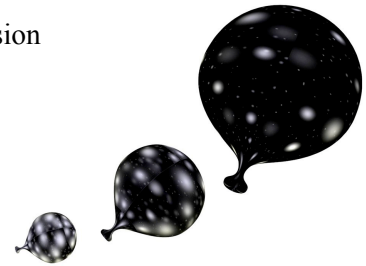
The Universe is expanding, but we are not. Why?

a) We are special.
b) We are grounded by our understanding of the Universe.
c) We are held together by stronger local forces.
d) What are you talking about, we are expanding.
e) The Universe is just no longer expanding.

~~Expanding into What?~~

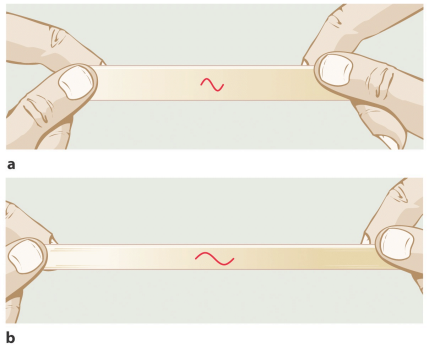
Common Misconception

- Its common to think of the expansion of the Universe like an explosion
  - Galaxies hurled away from each other through space
- This is incorrect!
- Einstein's Theory of Relativity tells us that spacetime itself is expanding!
  - Like an inflating balloon



Analogy - Rubber Band

- Spacetime expands, like stretching a rubber band
- Not only do distances grow…
- Even the photons' wavelengths get stretched!
  - Increasing wavelength = redshift!
  - **Cosmological redshift**



Reality

- The analogies are just to help us visualize, don't get stuck in the specifics.
- The Universe has no center.
- The Universe has no edge.
- Concept of time and space began with the Universe, can not apply the concepts so easily.

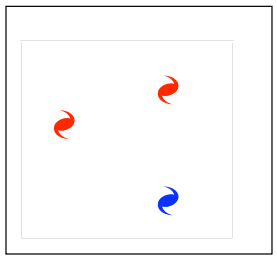
http://universe.gsfc.nasa.gov/images/reach-for-the-universe.jpg

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?

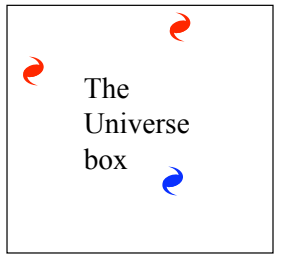
As the Universe expands:

- $M_{tomorrow}$ 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.

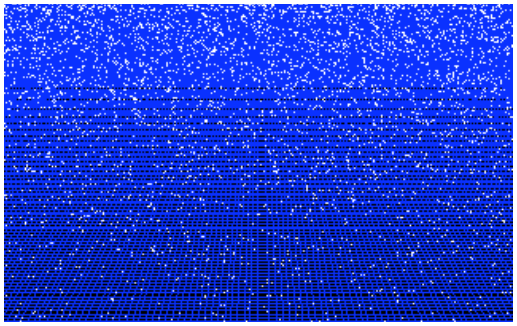
The origin of the Universe can be described by the idea of the Big Bang. Where did the Big Bang happen? Remember the Universe is homogenous & isotropic.

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

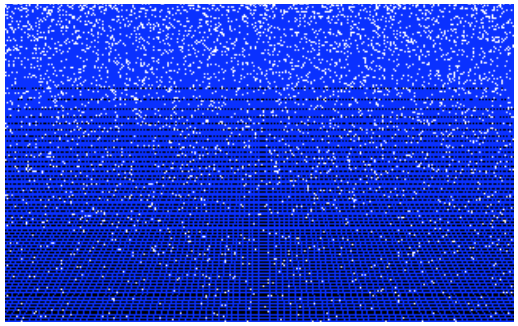
The Big Bang

- 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



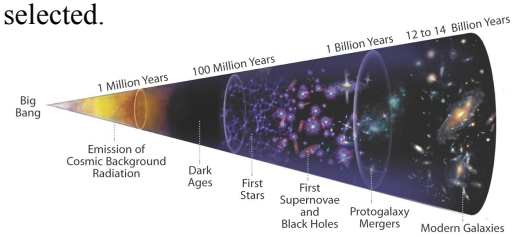
The Big Bang

- 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!**



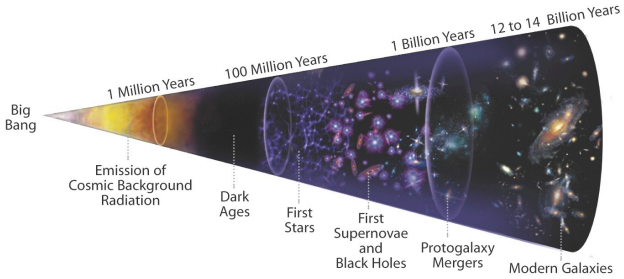
The Big Bang

- 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.

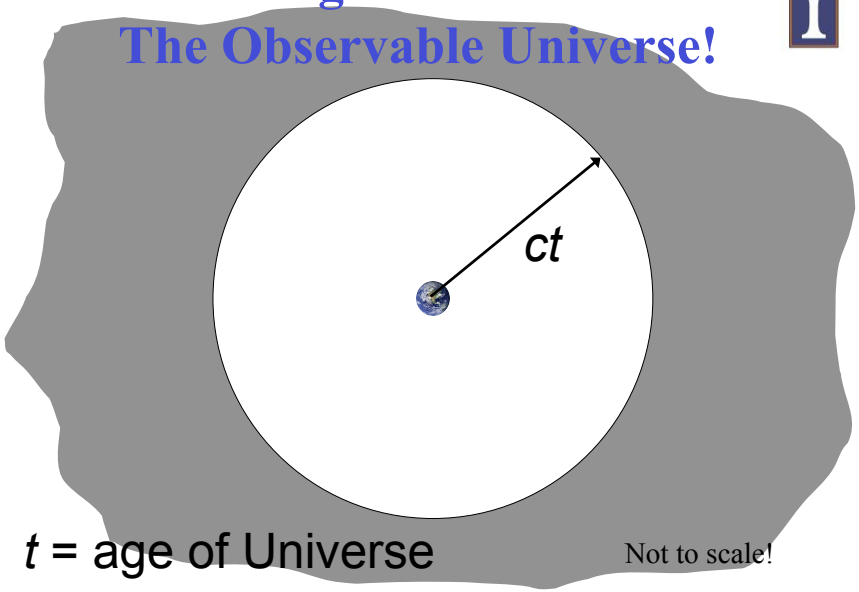


Question

Where did the Big Bang occur?

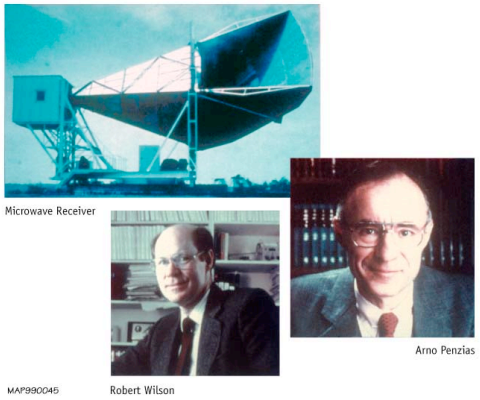
a) Everywhere.
b) At the edge of the Universe.
c) Just a little past the edge of the observable Universe.
d) Somewhere in the outer region of the Milky Way.
e) Snyder Hall, last Saturday night, 11:33 pm.

Looking Back in Time: The Observable Universe!

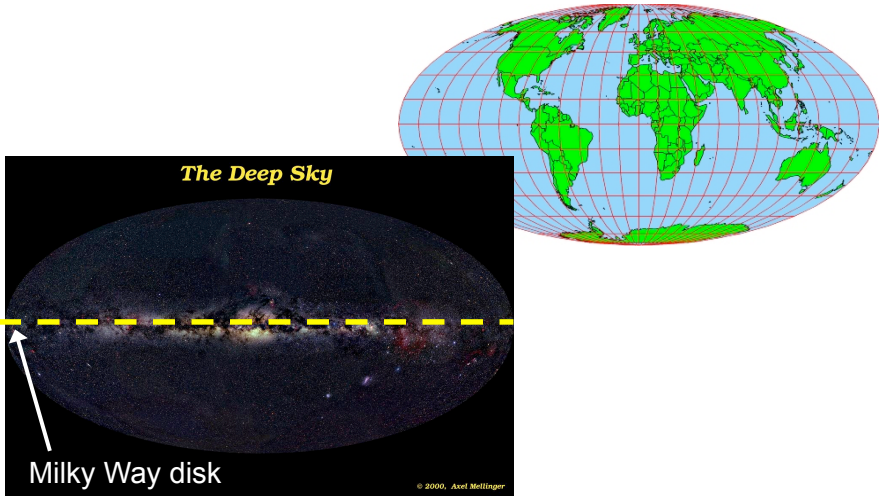


The Early Universe was *HOT*!

- 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.

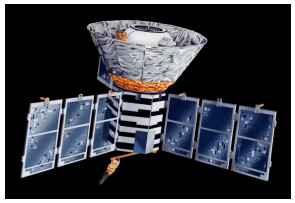


How to Understand Sky Maps

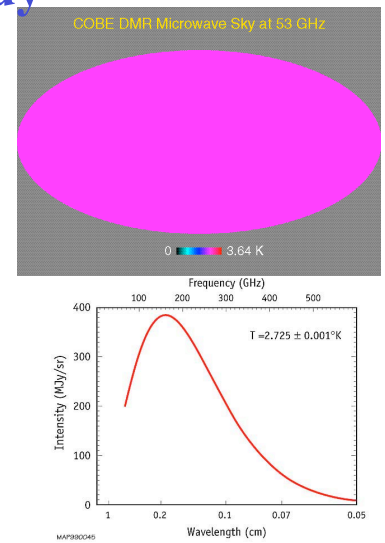


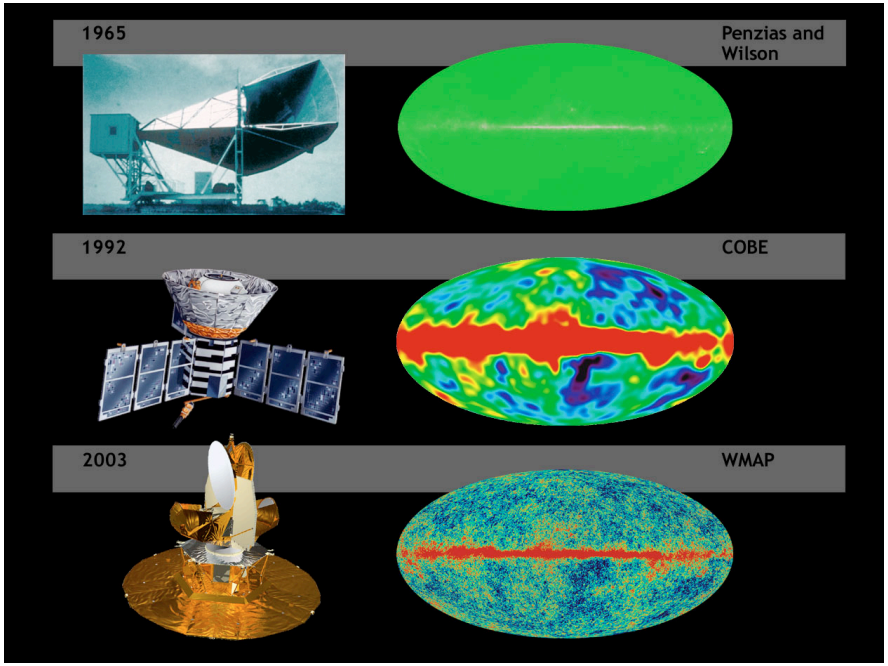
In Fact, a Rather Uniform Blackbody

- 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

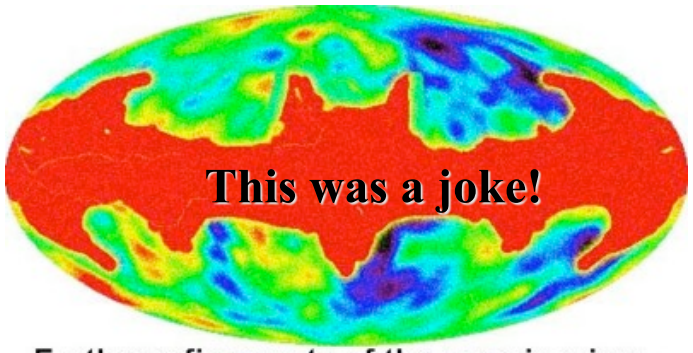


Cosmic Background Explorer (COBE) satellite (launched 1989)



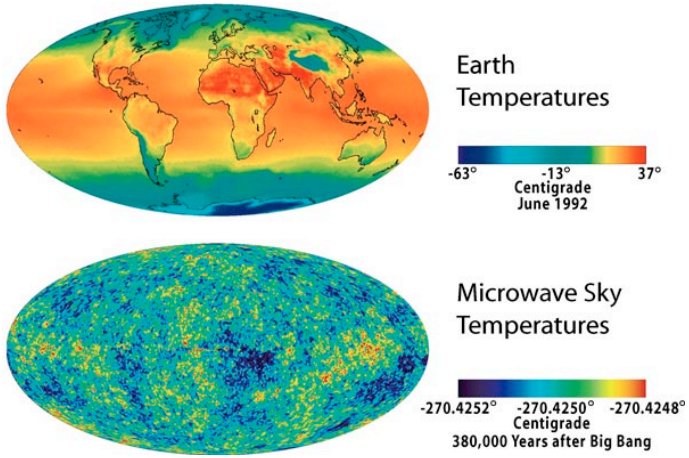


Unknown Fluctuations…

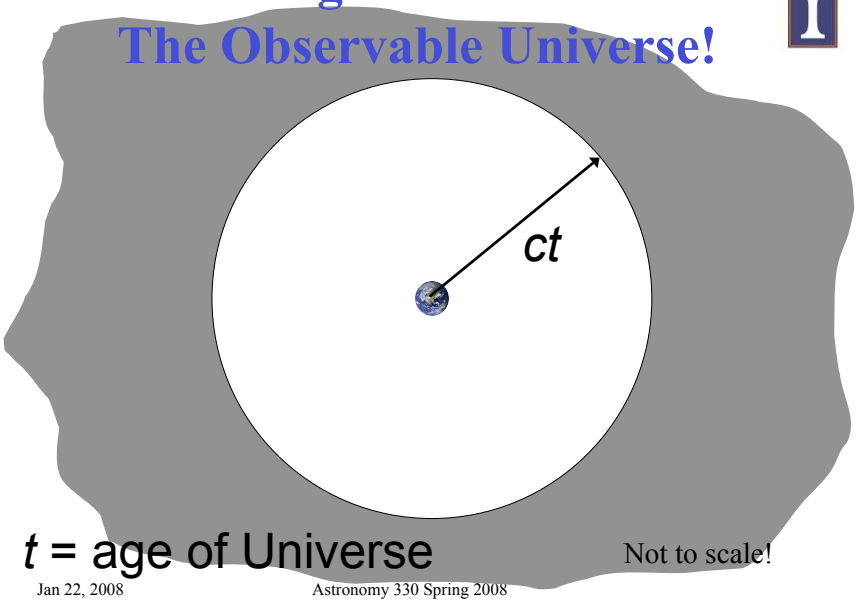


Further refinements of the cosmic microwave background reveal a deeper meaning for physicists to ponder.

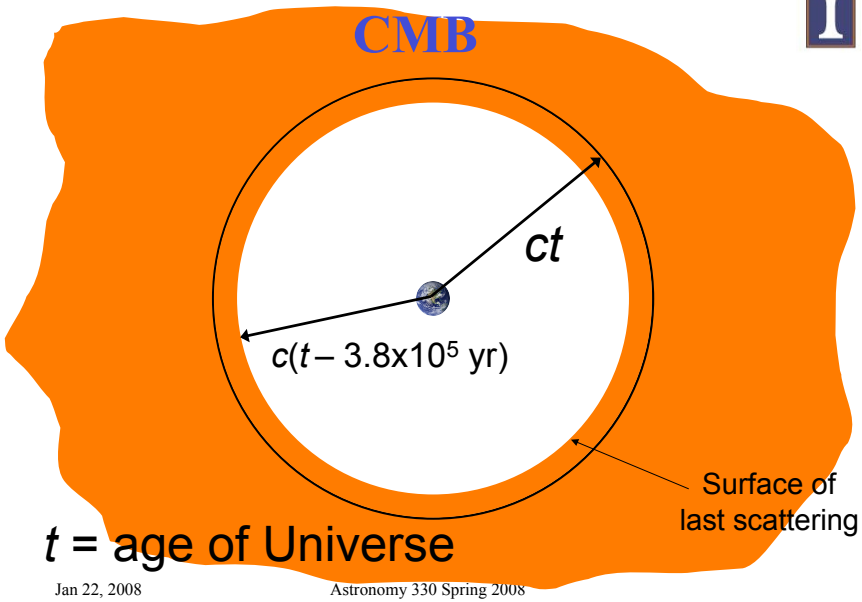
WMAP took a "baby picture" of the Universe– only 400000 yrs old.



Looking Back in Time: The Observable Universe!

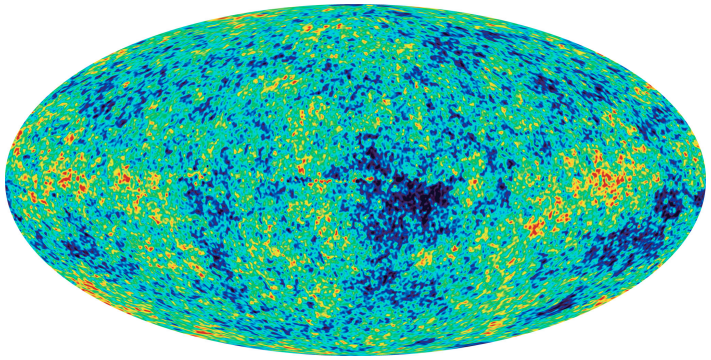


Looking Back in Time to the CMB



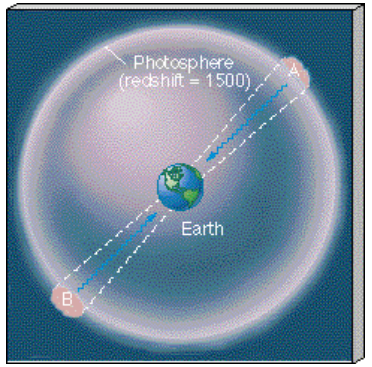
The Seeds of Galaxies

These small perturbations in temperature are the fluctuations (smaller than 1 in a 100000) 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.

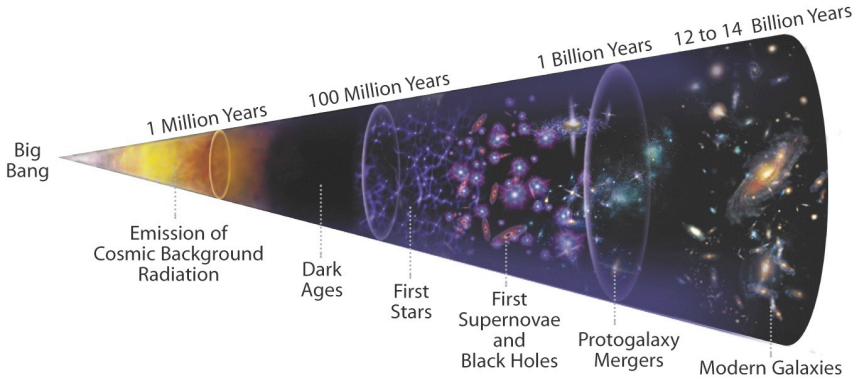


The Isotropy Problem

- 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

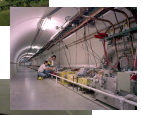
Since Big Bang works well so far, we have confidence to think about very early times:

$t << 1$ 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

Remember

- We are on a quest for HONC.
- The early Universe was too hot for any atoms to exist!
- Where did it all come from?

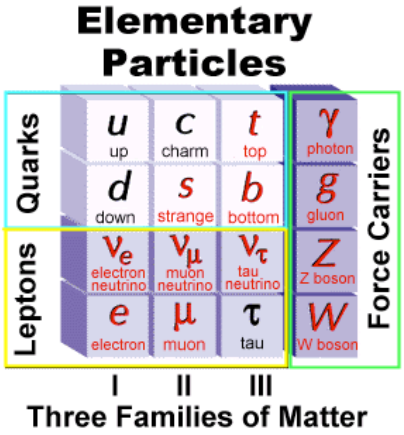
A Little Background Info

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

1. Basic Particles
2. Matter and Anti-matter

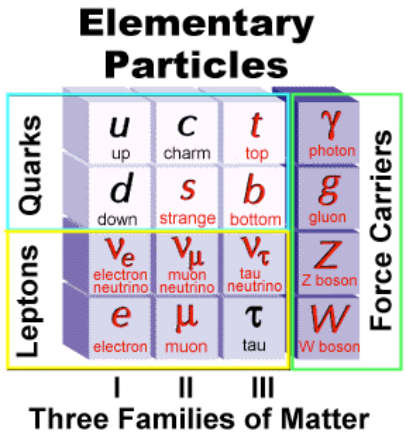
Basic Particles

- 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



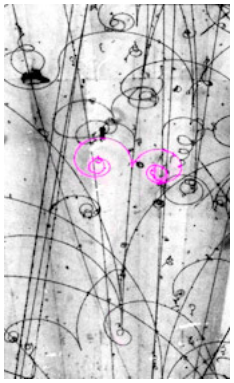
http://sol.sci.uop.edu/~jfalward/elementaryparticles/elementaryparticles.html

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

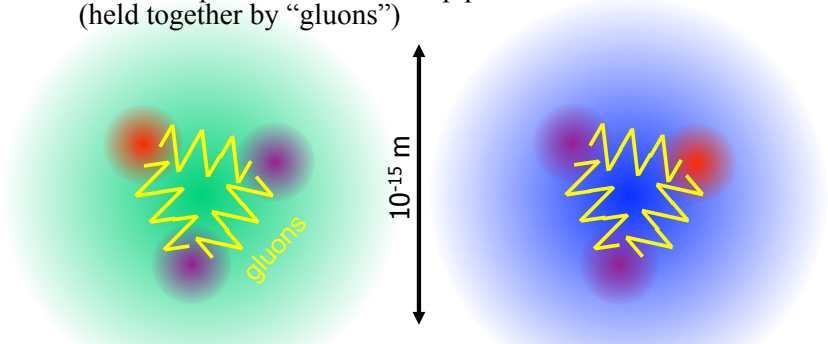


Matter & Anti-Matter

- 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!

Quarks

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



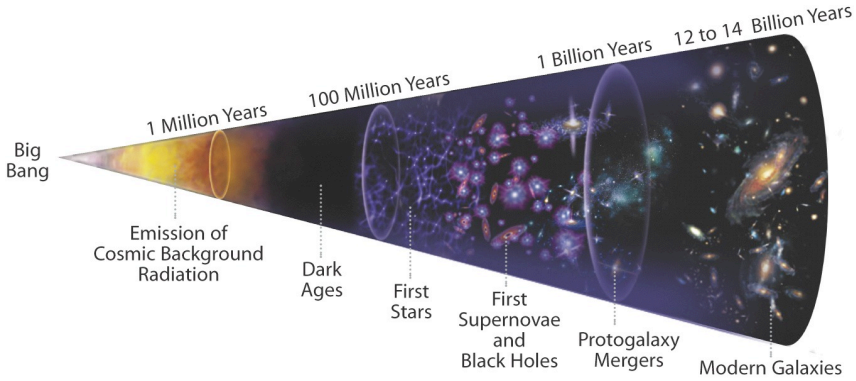
Proton (charge +1) =
2 "up" quarks (+4/3) +
1 "down" quark (-1/3)

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

Point

- H is made up of a proton
- So, we have to get the quarks to cool down and get together…
- A social for particles…

A Brief History of Time

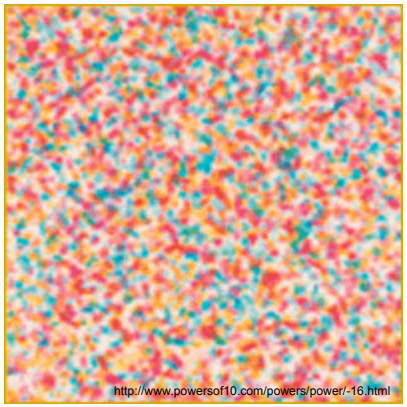


The First Instant (to 10^{-43} sec)

- Incredibly hot (more that 10^{32} K)
- Want a Nobel Prize? Develop a theory to describe this era of the Universe!

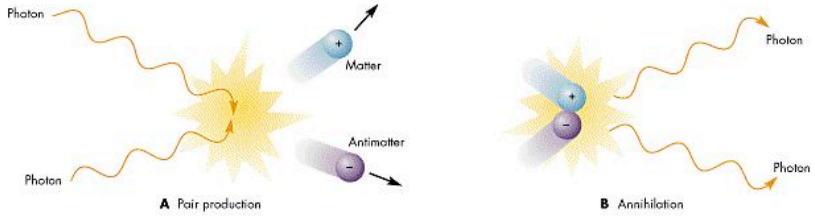
The GUT Era (until 10^{-35} sec)

- GUT = "Grand Unified Theory"
- Sea of free quarks (and anti-quarks) + photons + other basic particles
- Random fluctuations in density



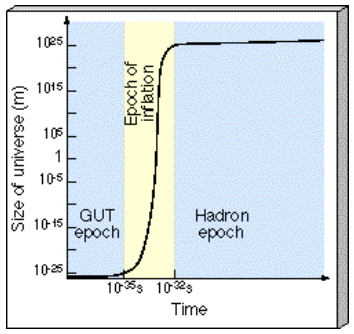
Matter and Anti-Matter

- 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



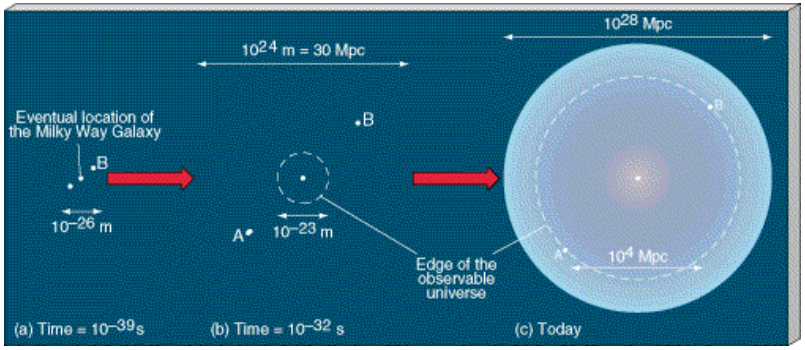
Inflation (10^{-35} to 10^{-32} sec)

- Universe went through a period of extremely rapid expansion
- Expansion by more than a factor of $\mathbf{10^{50}}$!!
- Areas that were close before inflation were now separated by millions of parsecs!



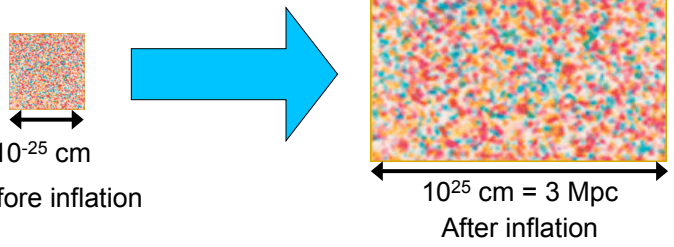
Inflation Solves the Isotropy Problem!

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



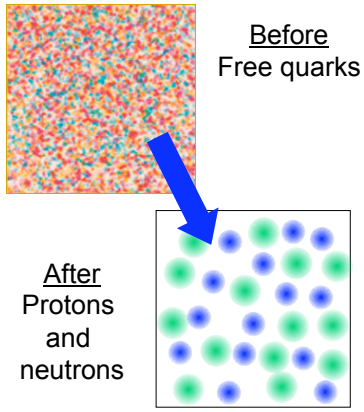
Origin of the CMB Fluctuations

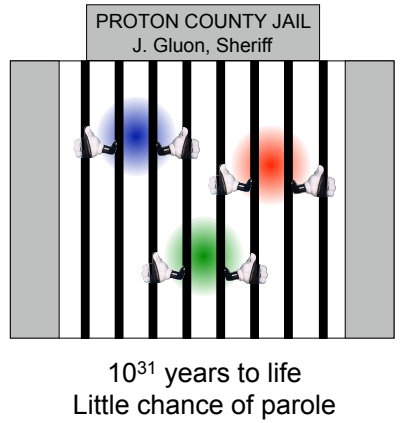
- Early Universe: a sea of particles & energy
- Density was constantly fluctuating on microscopic scales
- Inflation: blew up microscopic fluctuations to galaxy-size



Quark Confinement

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





Question

The seeds of Galaxies were due to?

a) Large super structures in the early Universe.
b) Nuclear strong force fields.
c) Quantum fluctuations in quark density.
d) Gravitational instabilities in the fabric of space-time.
e) Unclear reasons.

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 first hydrogen atoms (ionized– no electrons— but there)**