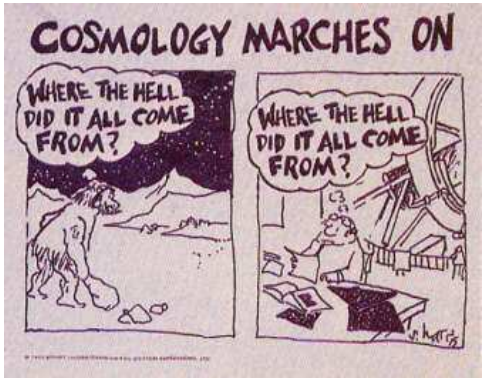
The History of the Universe in 200 Words or Less

Quantum fluctuation. Inflation. Expansion. Strong nuclear interaction. Particle-antiparticle annihilation. Deuterium and helium production. Density perturbations. Recombination. Blackbody radiation. Local contraction. Cluster formation. Reionization? Violent relaxation. Virialization. Biased galaxy formation? Turbulent fragmentation. Contraction. Ionization. Compression. Opaque hydrogen. Massive star formation. Deuterium ignition. Hydrogen fusion. Hydrogen depletion. Core contraction. Envelope expansion. Helium fusion. Carbon, oxygen, and silicon fusion. Iron production. Implosion. Supernova explosion. Metals injection. Star formation. Supernova explosions. Star formation. Condensation. Planetesimal accretion. Planetary differentiation. Crust solidification. Volatile gas expulsion. Water condensation. Water dissociation. Ozone production. Ultraviolet absorption. Photosynthetic unicellular organisms. Oxidation. Mutation. Natural selection and evolution. Respiration. Cell differentiation. Sexual reproduction. Fossilization. Land exploration. Dinosaur extinction. Mammal expansion. Glaciation. Homo sapiens manifestation. Animal domestication. Food surplus production. Civilization! Innovation. Exploration. Religion. Warring nations. Empire creation and destruction. Exploration. Colonization. Taxation without representation. Revolution. Constitution. Election. Expansion. Industrialization. Rebellion. Emancipation Proclamation. Invention. Mass production. Urbanization. Immigration. World conflagration. League of Nations. Suffrage extension. Depression. World conflagration. Fission explosions. United Nations. Space exploration. Assassinations. Lunar excursions. Resignation. Computerization. World Trade Organization. Terrorism. Internet expansion. Reunification. Dissolution. World-Wide Web creation. Composition. Extrapolation?

Astronomy 122



This Class (Lecture 27):

Dark Matter & Dark Energy
ICES Form!!!

Next Class:

The End

HW11 due next Wednesday!!!

Music: *The Universe Song* – Animaniacs

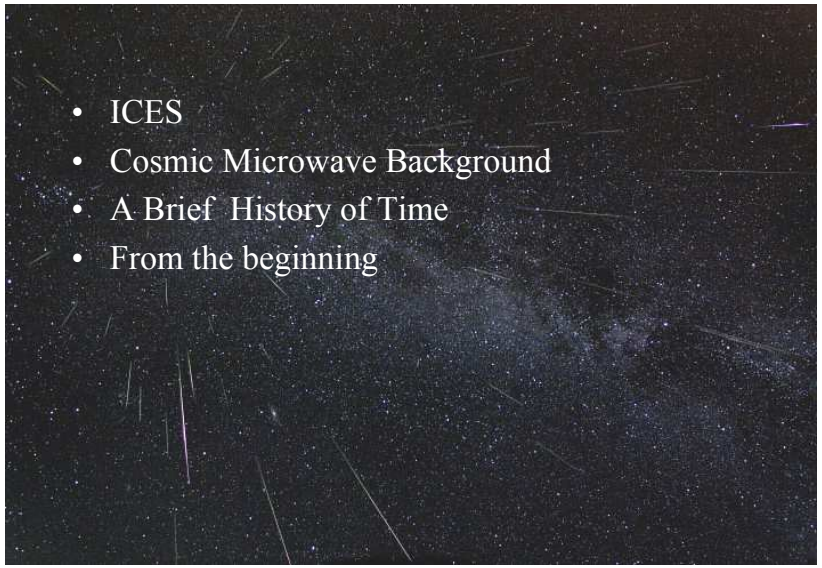
Final Exam

- In this classroom, May 6th from 1:30-4:30pm
- Multiple choice 70 questions.
- Can bring one sheet of notes
- Can bring a calculator if you want.
- Will be cumulative (80% new material)
  - 56 from the new and 14 from the old.
  - The old parts should be relevant to new discussions.
- Will post the study guide as soon as its finished.

OBAFGKM Contest

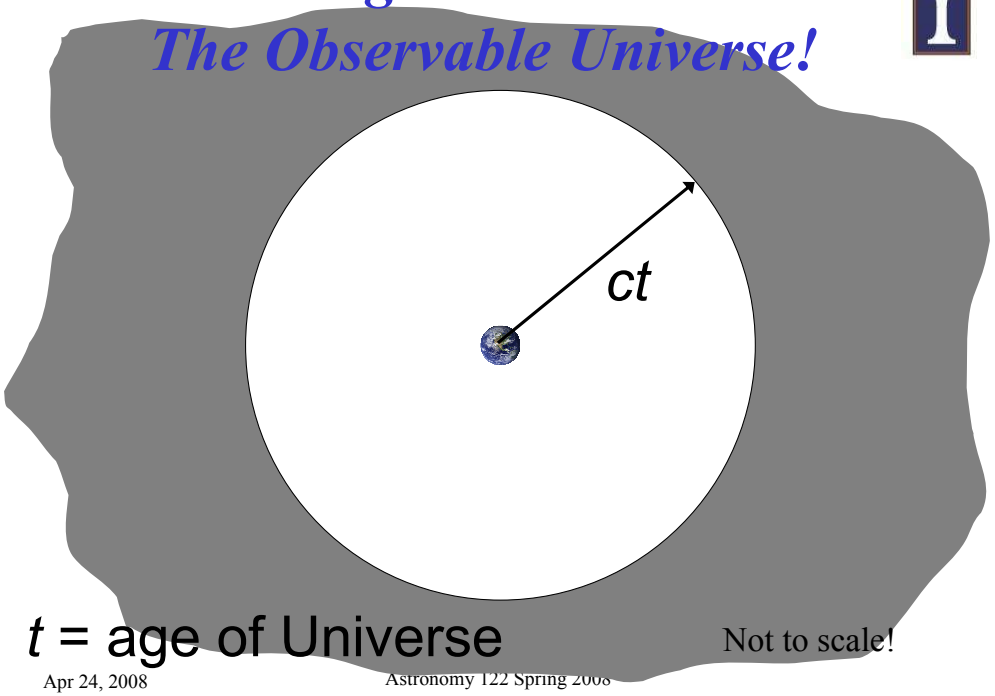
- Spring 2008 Contest

Outline



- ICES
- Cosmic Microwave Background
- A Brief History of Time
- From the beginning

Looking Back in Time: The Observable Universe!

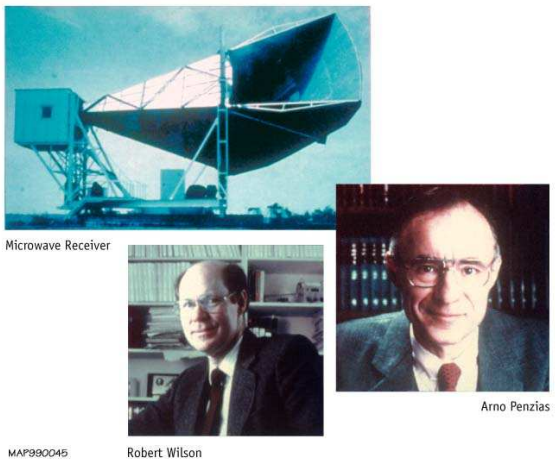


t = age of Universe

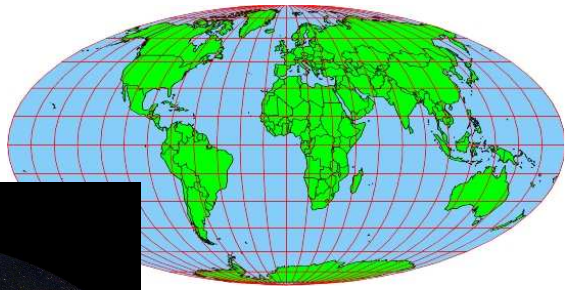
Not to scale!

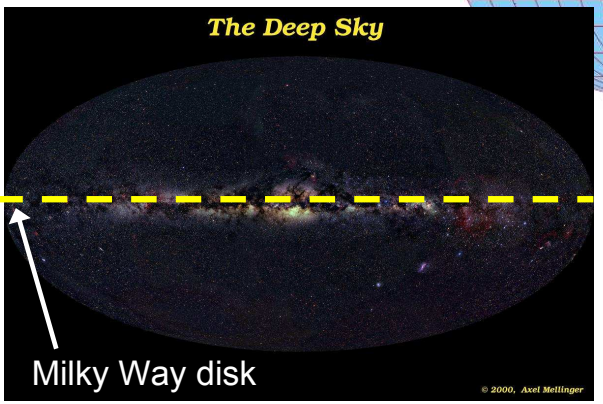
The Early Universe was HOT!

- 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 millimeter wavelengths.
- Now, it is called the Cosmic Microwave Background (CMB).
- First detected by Robert Wilson and Arno Penzias.



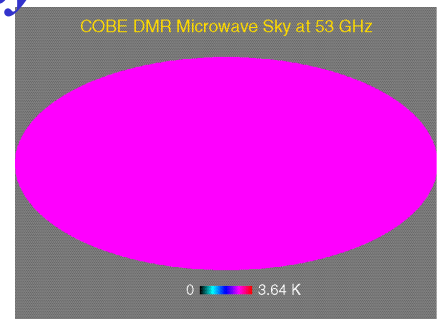
How to Understand Sky Maps



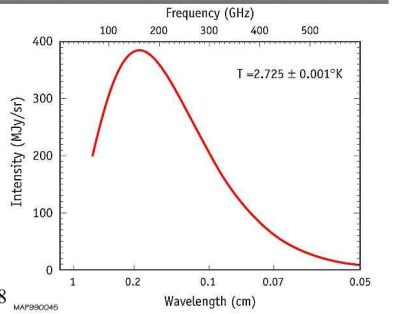


In Fact, a Rather Uniform Blackbody

- 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)



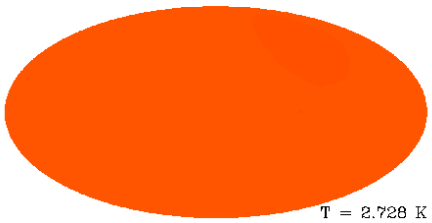
Question

If you look in any direction in the sky, we measure 2.7 K to high precision. How can that be?

a) It is due to pigeon droppings.
b) It is the residual of the Big Bang
c) It is a direct result of the temperature of the initial cloud in which the Solar System was formed.
d) It is the temperature of the residual circumstellar disk in our Solar System.

Small Scale Variations

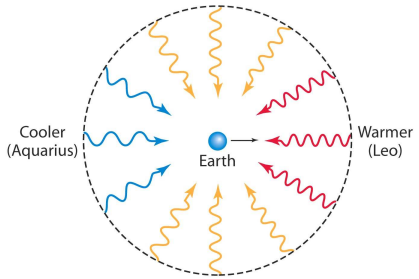
- There are small scale variations in the CMB.
- Largest variations are due to motions
  - Motions of the Sun around the Galaxy
  - Motions of the Galaxy in the Local Group
  - Motions of the Local Group in our supercluster

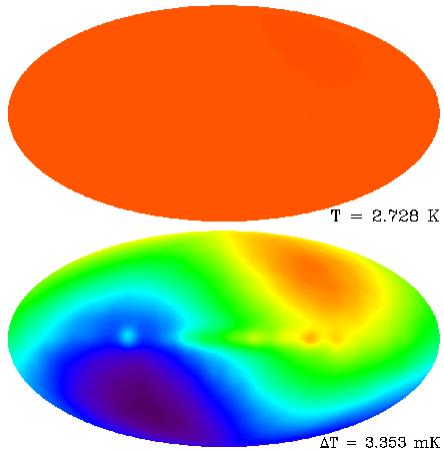


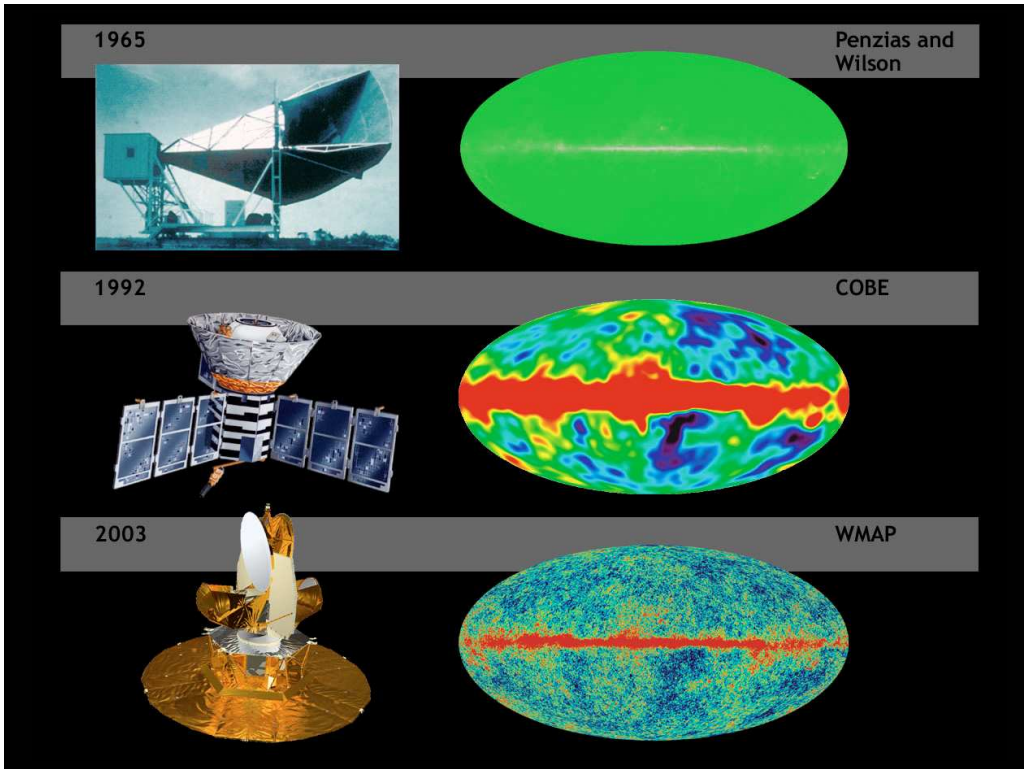
- There are also Galactic sources of microwave radiation
- First, we have to remove these variations…
  - What is left is cosmological - from the Big Bang

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

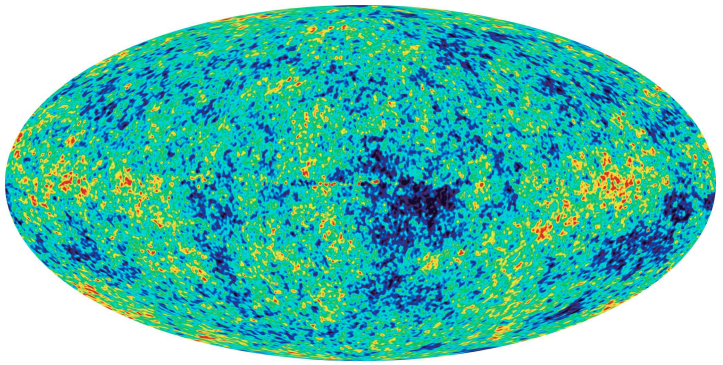






Small Scale Variations - Cosmological

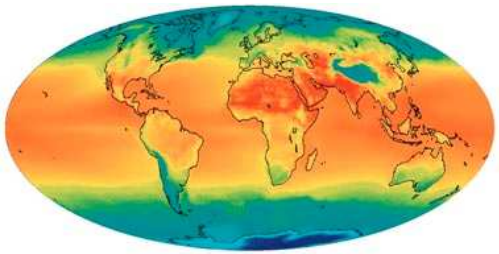
Cosmological variations are less than 1 part in 100,000!



Unknown Fluctuations…

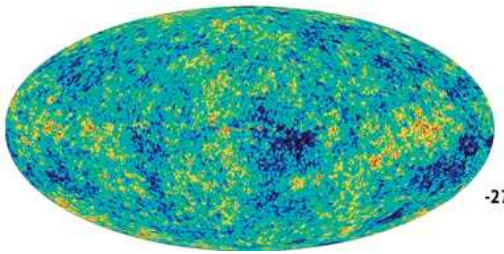
Further refinements of the cosmic microwave background reveal a deeper meaning for physicists to ponder.

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



Earth Temperatures

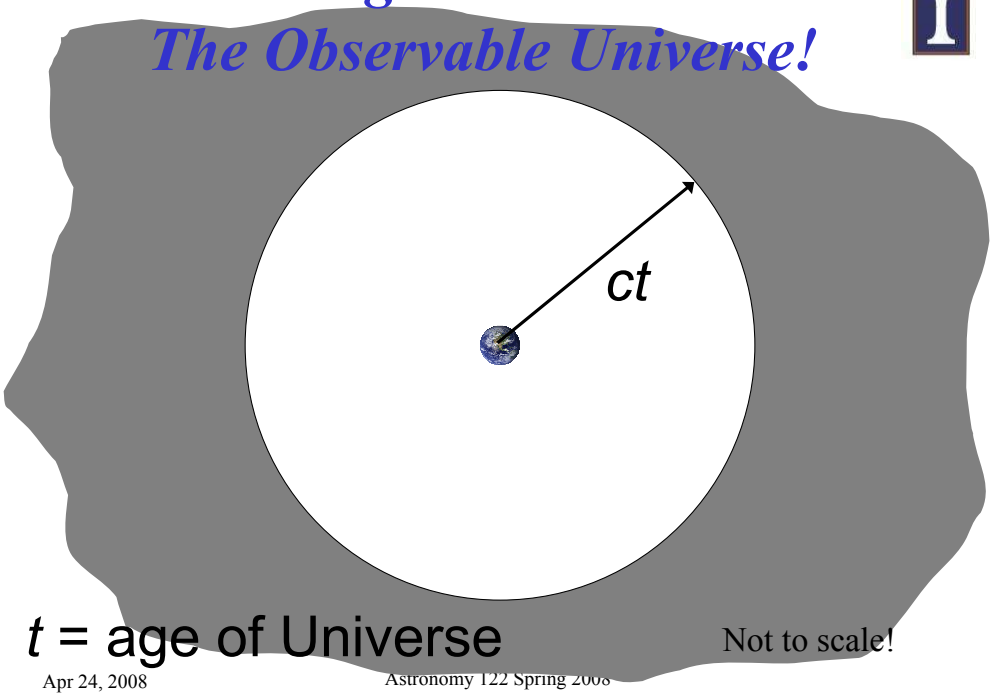
-63° -13° 37°
Centigrade
June 1992



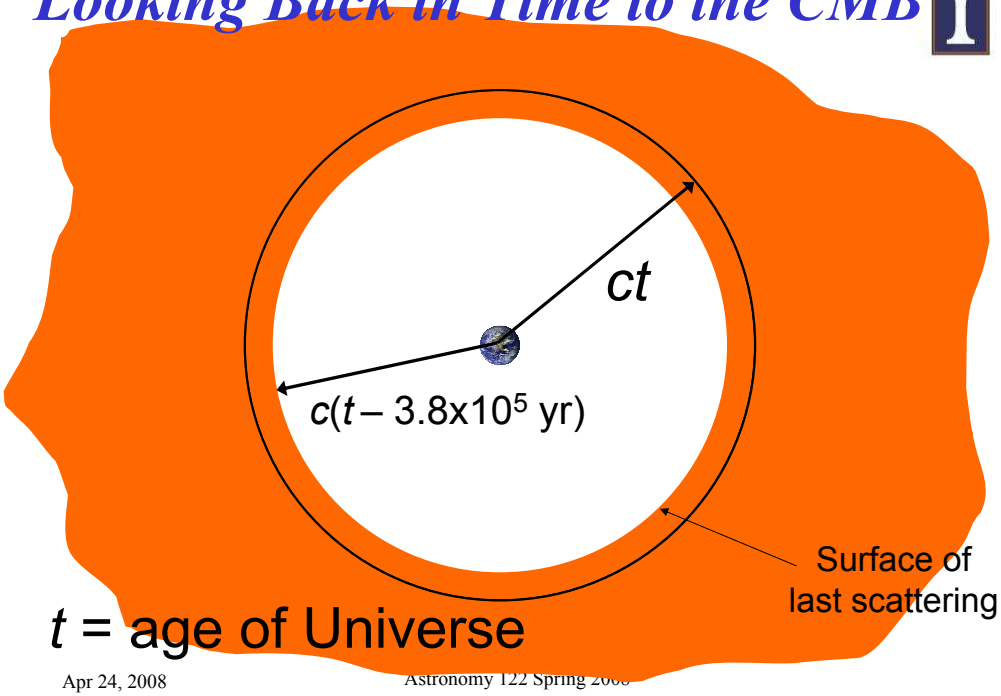
Microwave Sky Temperatures

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

Looking Back in Time: The Observable Universe!

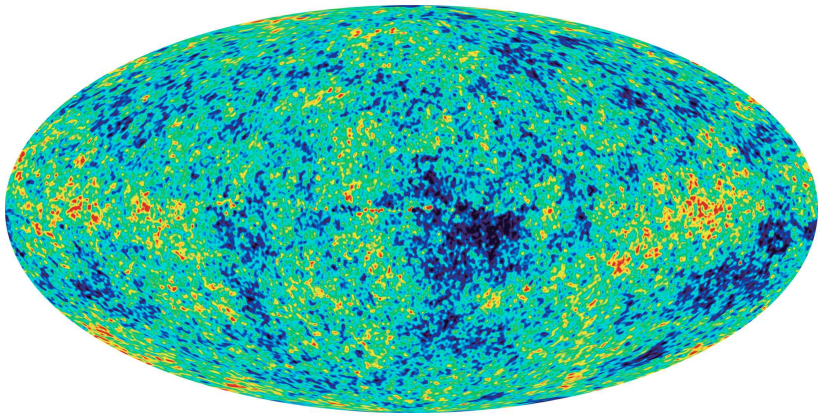


Looking Back in Time to the CMB

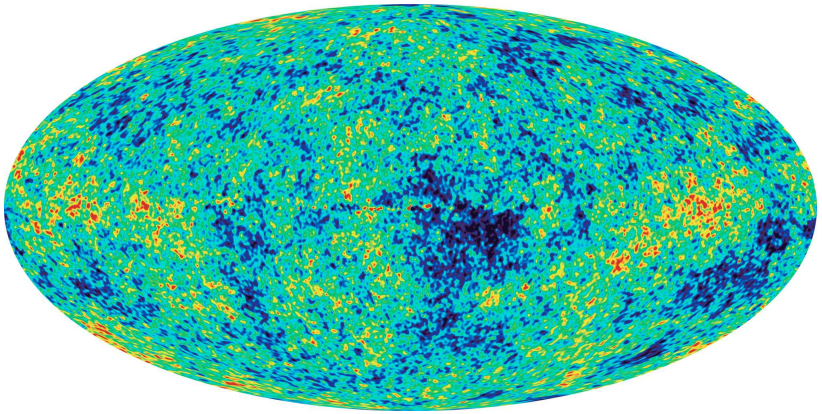


The Seeds of Galaxies

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



Galaxy Structure



Galaxy Formation Simulation

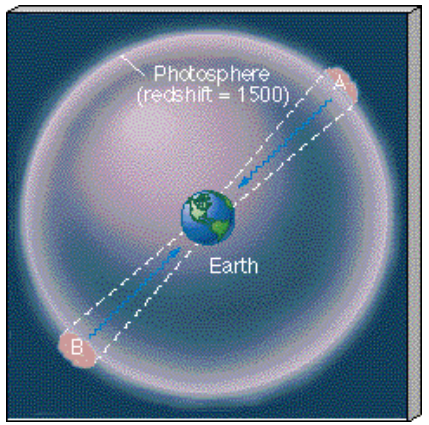
Question

The CMB is not exactly uniform, there are small perturbations (1 part in 100,000). If we did not have those

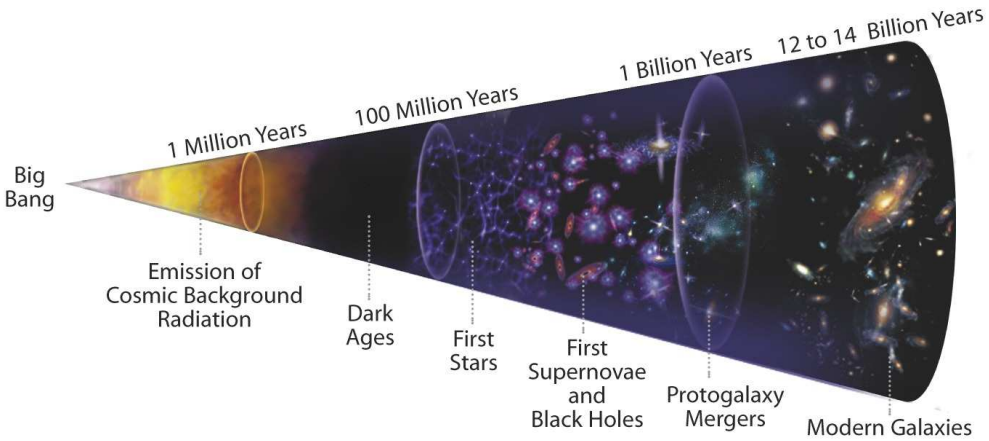
a) Galaxies would never have formed.
b) The CMB would have been boring.
c) The sky would be exactly 2.73 Kelvin.
d) The large scale structure of superclusters would have looked more like a uniform sponge cake instead of soap bubbles.

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

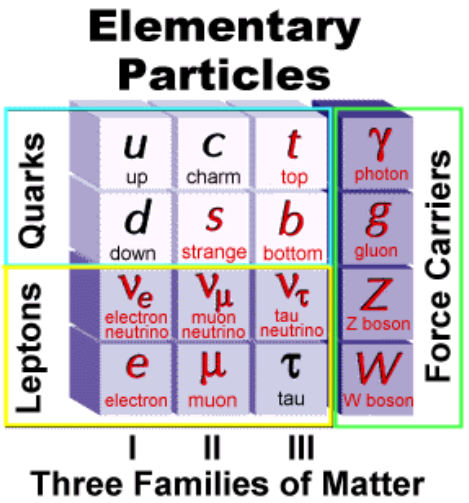
A Little Background Info

To 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

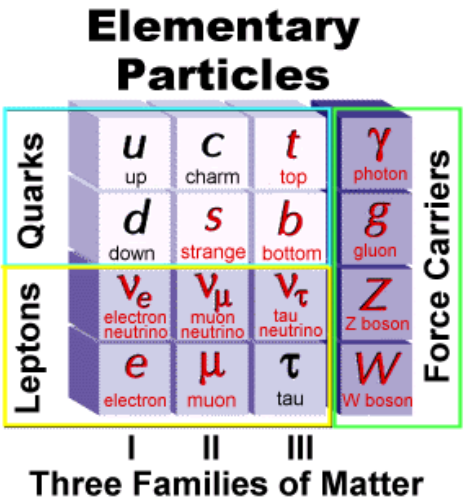
Basic Particles

- 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



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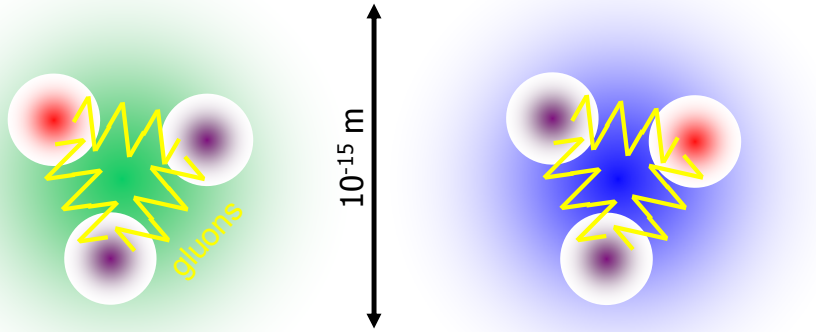
Quarks

- 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)

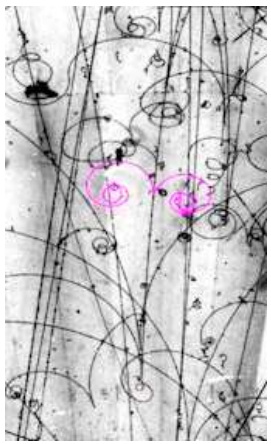
Neutron (charge 0) =
1 "up" quark (+2/3) +
2 "down" quarks (-2/3)

The Universe is Made of Matter

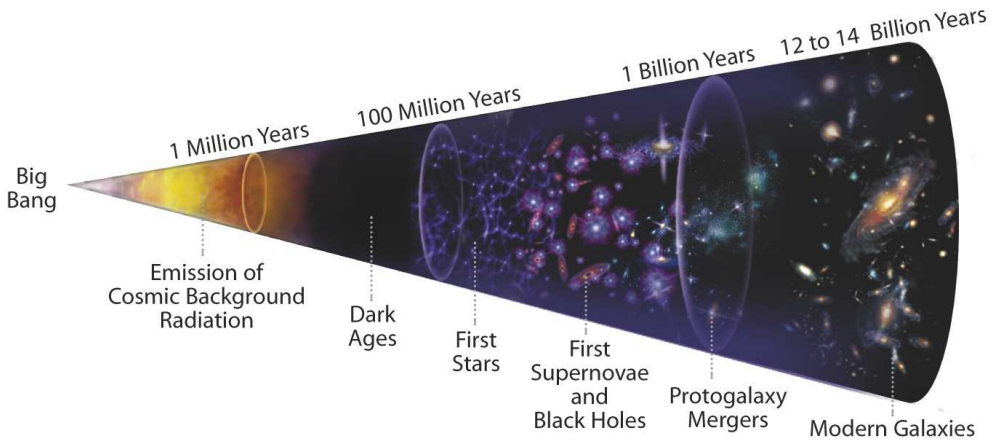
- You, and I, and the Earth are all made of matter not anti-matter
- The Moon is made of matter, not anti-matter
- Local "neighborhood" in Milky Way is matter, gas between the stars
- The Universe is made of matter
- How did this come to be?

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!

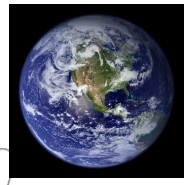
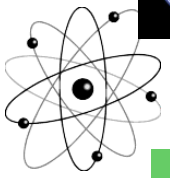


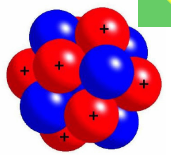
A Brief History of Time



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

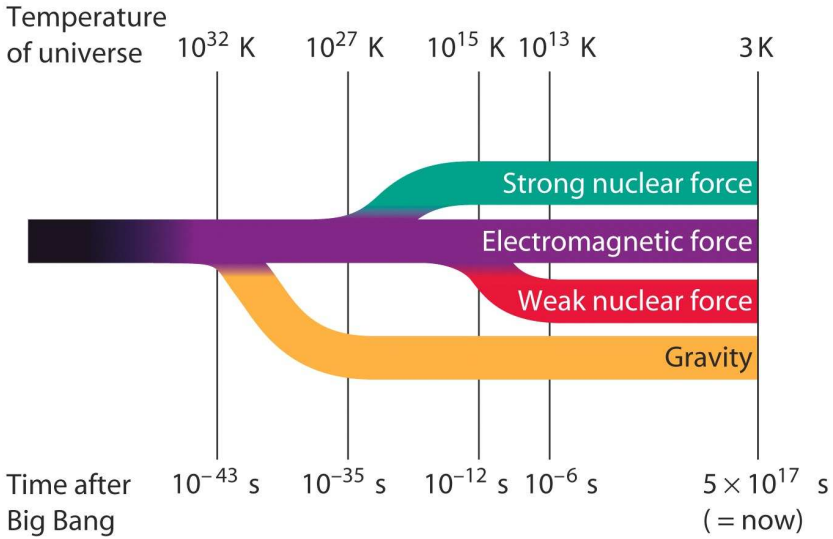





The First Instant (to 10^{-43} sec)

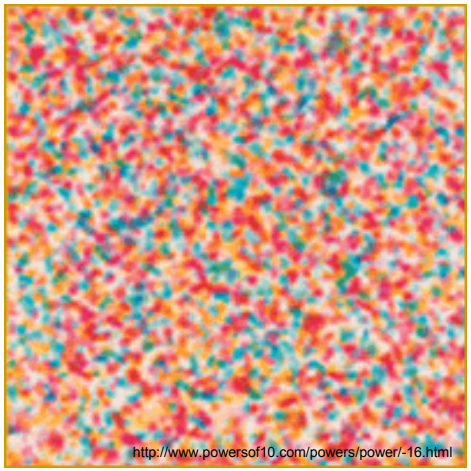
- Incredibly hot (more that 10^{32} K)
- Our current hypothesis – only one force in nature
  - The four forces were unified
  - Remains to be proven, as the theories we use to describe nature don't work in this era
- At the end of this era, gravity became a separate force
- Want a Nobel Prize? Develop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

Dis-Unification of the Forces



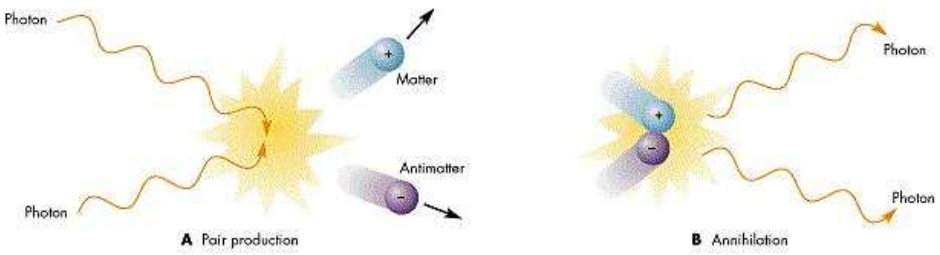
The GUT Era (until 10^{-35} sec)

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



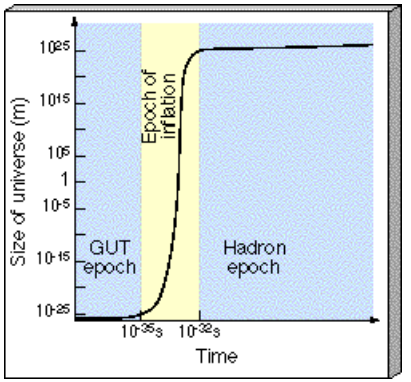
Matter and Anti-Matter

- 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)

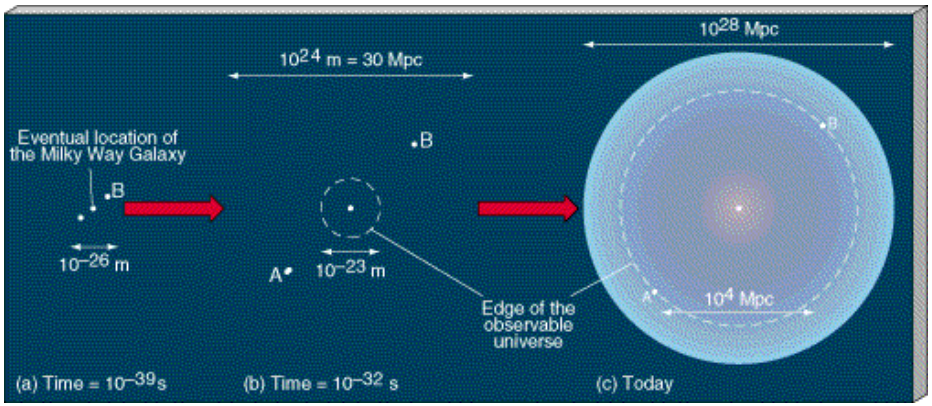
- Universe went through a period of extremely rapid expansion
- Expansion by more than a factor of **10^{50}!!**
- Expansion driven by the splitting of strong and electro-magnetic/weak forces



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

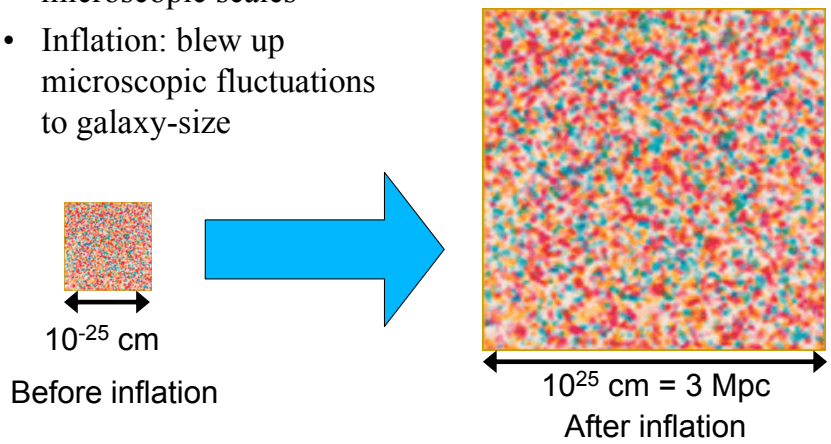
Inflation Solves the Isotropy Problem!

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

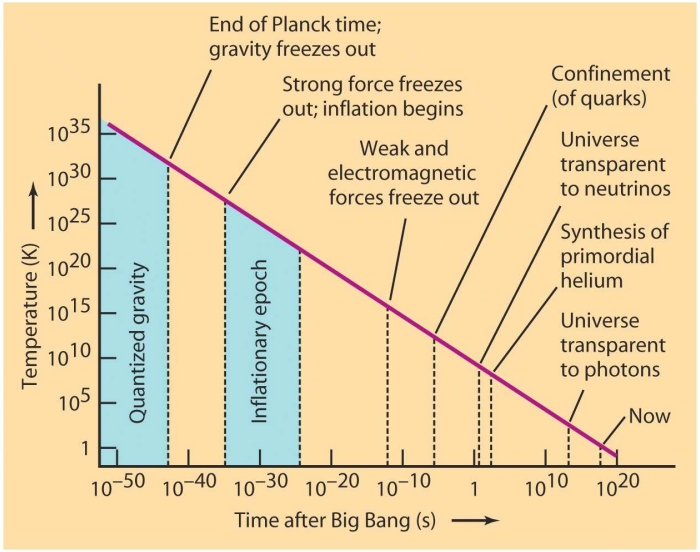


Origin of the CMB Fluctuations

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

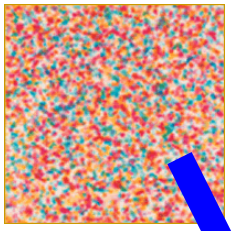


The End of the First Second

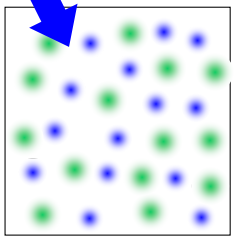


Quark Confinement

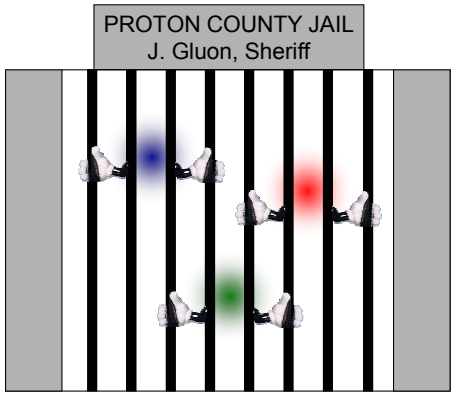
- 10^{-6} seconds: free quarks condensed into protons and neutrons



Before
Free quarks



After
Protons and neutrons



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