Astronomy 150:

Killer Skies

This Class (Lecture 33):
The Early Universe

Next Class:
The End of the Universe

HW 11 due on Dec 5th

Music: The Universe is You–
Sophie Ellis-Bextor

How Far?

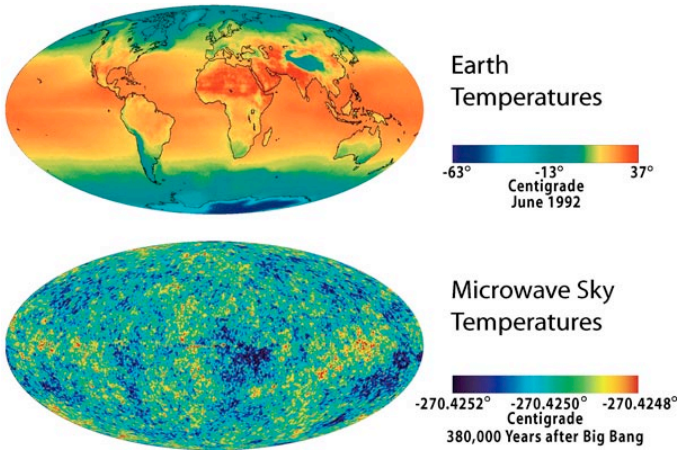
How far away from this classroom will you be for Thanksgiving?

a) 0-10 miles
b) 10-100 miles
c) 100-1000 miles
d) 1000+ miles

Outline

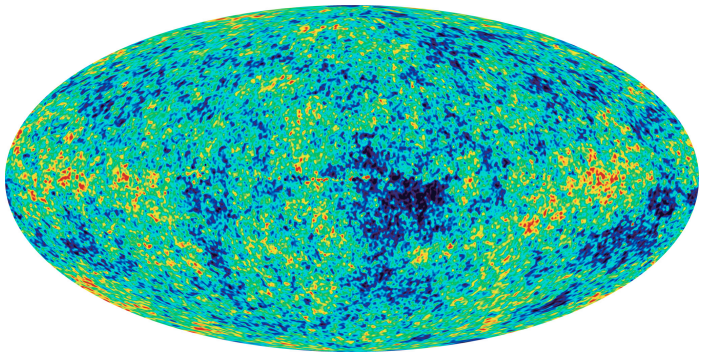
- The Early Universe
  - Making the first Atoms

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

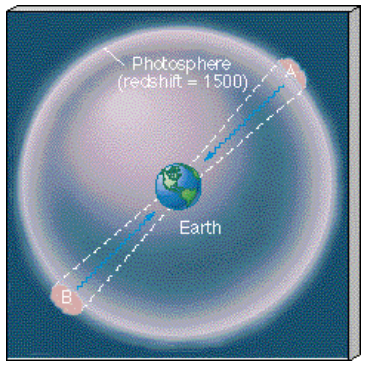


The Seeds of Galaxies

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.

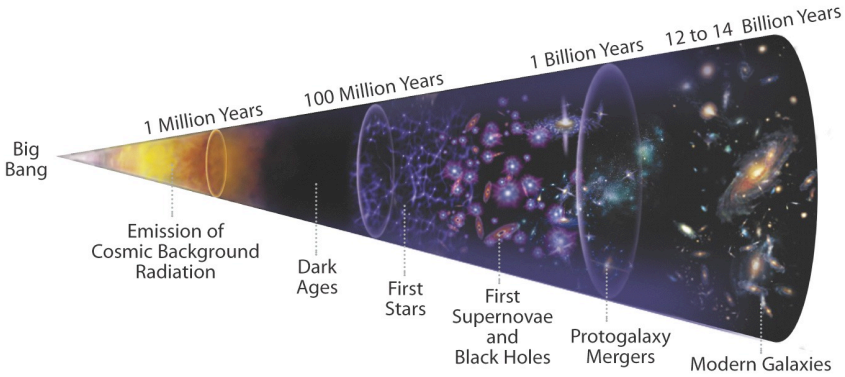


The Isotropy Problem



- 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



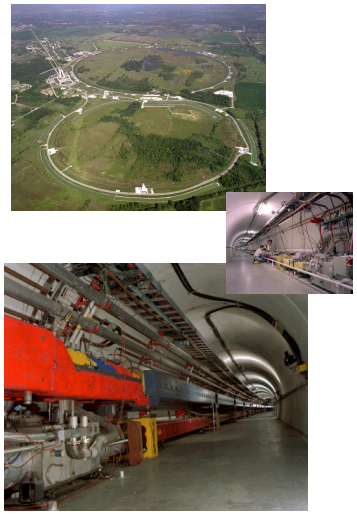
THE VERY EARLY UNIVERSE

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

$t \ll 1$ sec !

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

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



Fermilab
(okay and also Cern)

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

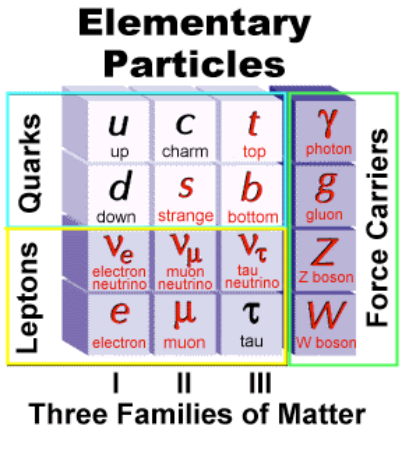
A Little Background Info

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

1. Basic Particles
2. Matter and Anti-matter

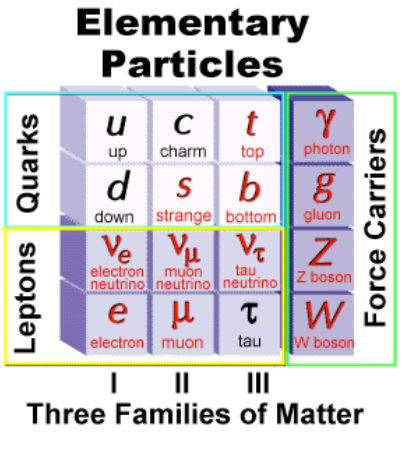
Basic Particles

- 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



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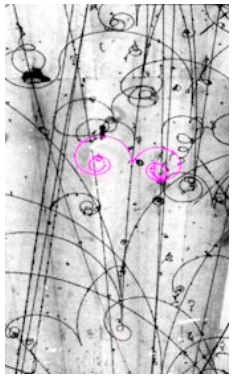
The Universe is Made of Matter

- 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

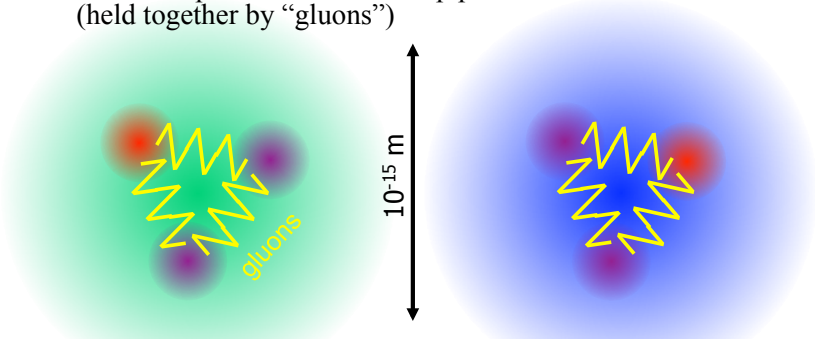


Matter & Anti-Matter

- 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")

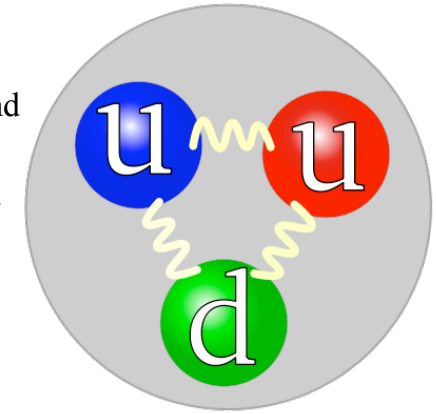


Proton (charge +1) =
2 "up" quarks (+4/3) +
1 "down" quark (-1/3)

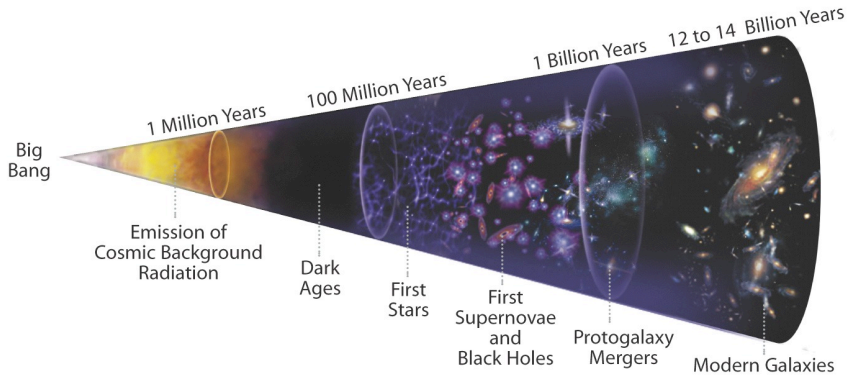
Neutron (charge 0) =
1 "up" quark (+2/3) +
2 "down" quarks (-2/3)

Point: Proton = 3 quarks!

- H is made up of a proton and an electron.
- Electrons are around at this point, but no protons yet.
- So, we have to get the quarks to cool down and get together…
- A social for particles…



A Brief History of Time

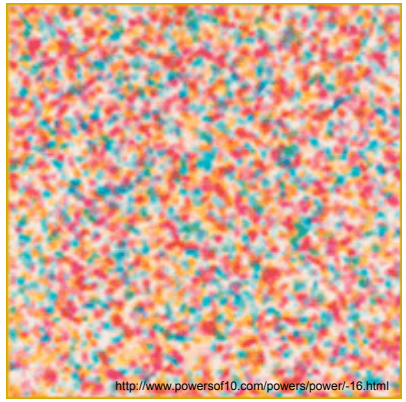


The First Instant (to 10^{-43} sec)

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

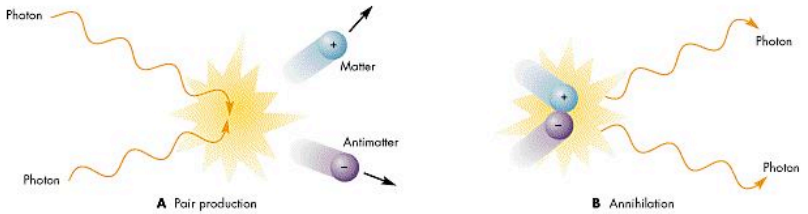
The GUT Era (until 10^{-35} sec)

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



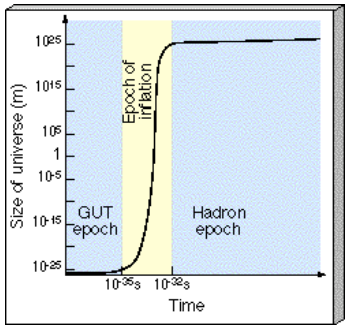
Matter and Anti-Matter

- 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



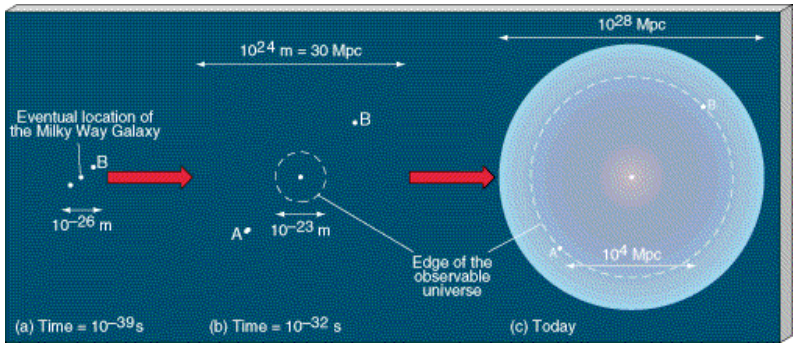
Inflation (10^{-35} to 10^{-32} sec)

- 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!



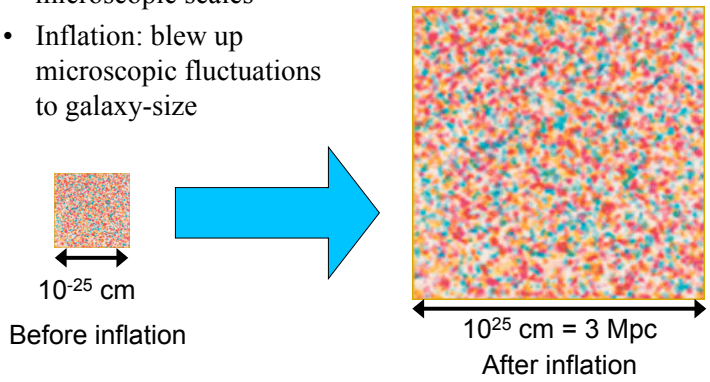
Inflation Solves the Isotropy Problem!

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



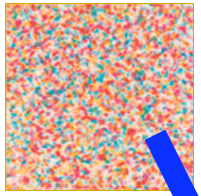
Origin of the CMB Fluctuations

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

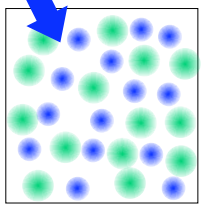


Quark Confinement

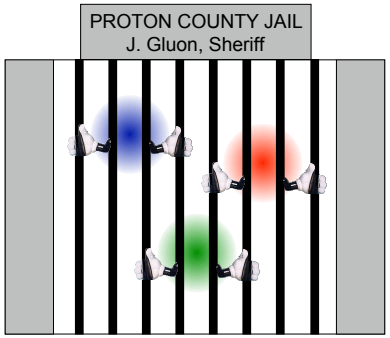
- 10^{-6} seconds: free quarks condensed into protons and neutrons



Before
Free quarks



After
Protons and neutrons



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

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.

The Universe

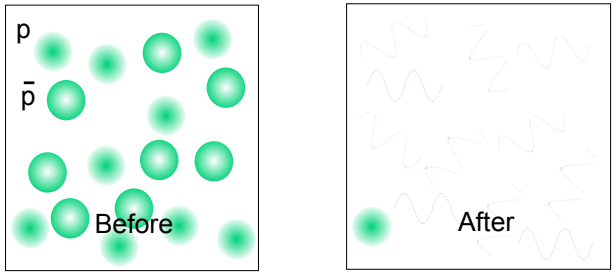
- Began with a Big Bang
  - 13.7 billion years ago
- Still expanding and cooling
  - The rate of expansion is known and something weird going on there
- It is BIG
  - As far as we are concerned, it is infinite in any direction
- The universe is homogeneous and isotropic
  - **Homogeneous** - The same "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!

The Universe: Timeline

- Big Bang: 13.7 billion years ago
- GUT era: $+10^{-35}$ second, energy and quarks
- Inflation: 10^{-35} to 10^{-32} seconds, Universe expands by more than 10^{50}!
- Quark confinement: 10^{-32} to 10^{-6} seconds, protons and neutrons form

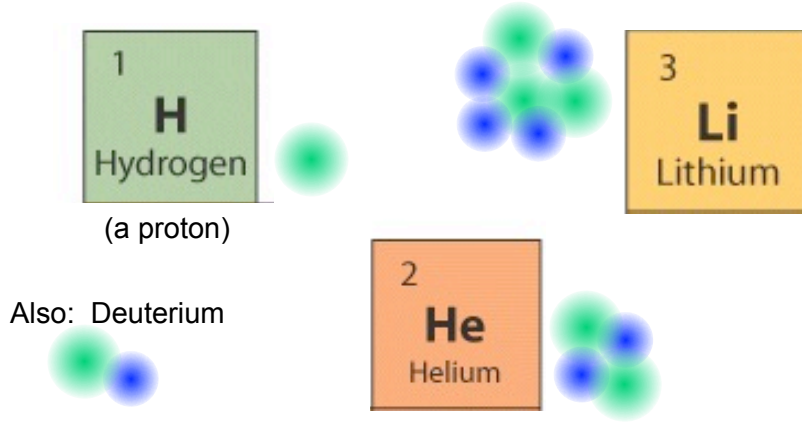
Annihilation of the Anti-matter

- 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)**

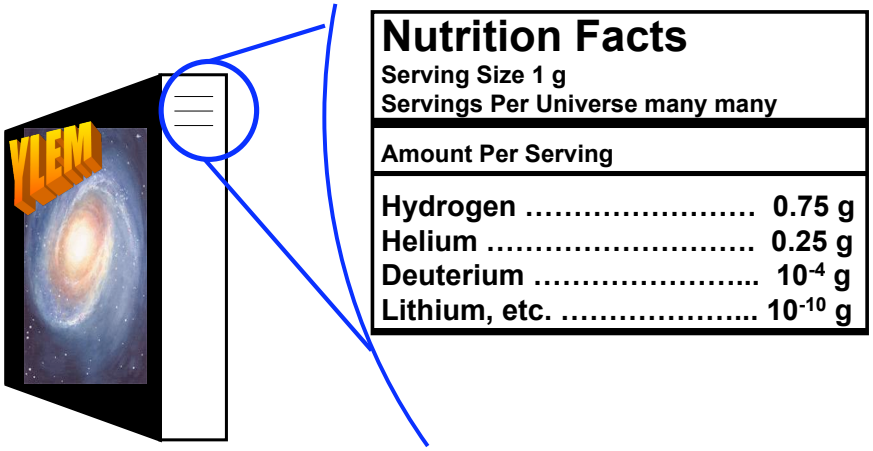


Big Bang Nucleosynthesis

When the Universe was 1 sec to 3 mins old, the temperature fell to 10^9 K and protons and neutrons can "shack-up" to form the first light elements.



End Result: Big Bang Correctly Predicts Abundances



Nutrition Facts

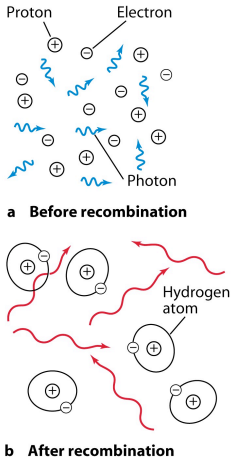
Serving Size 1 g
Servings Per Universe many many

Amount Per Serving

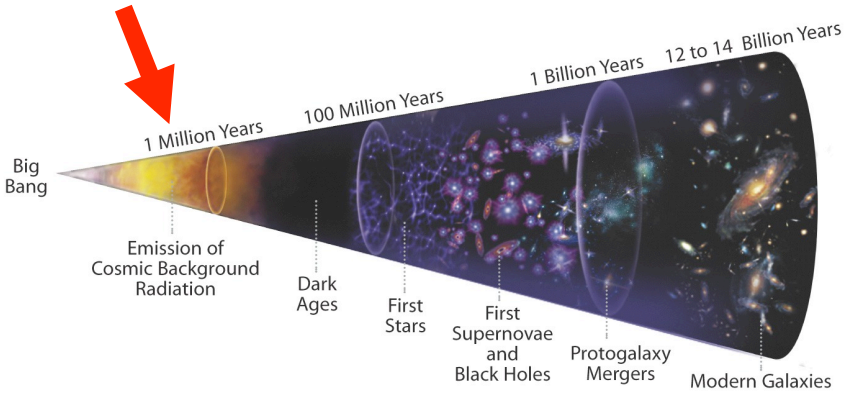
Hydrogen	**0.75 g**
Helium	**0.25 g**
Deuterium	**10^{-4} g**
Lithium, etc.	**10^{-10} g**

Era of Recombination

- In early Universe, photons were energetic, kept atoms ionized
  - protons and electrons couldn't make neutral hydrogen atoms
- After 380,000 years, photons couldn't ionize hydrogen anymore
  - Expansion of space stretched photons' wavelengths
  - Not enough energy to ionize hydrogen
  - Universe became transparent to photons
- This radiation is the source of the Cosmic Microwave Background!
- **The first H atoms proper!**



Origin of the CMB

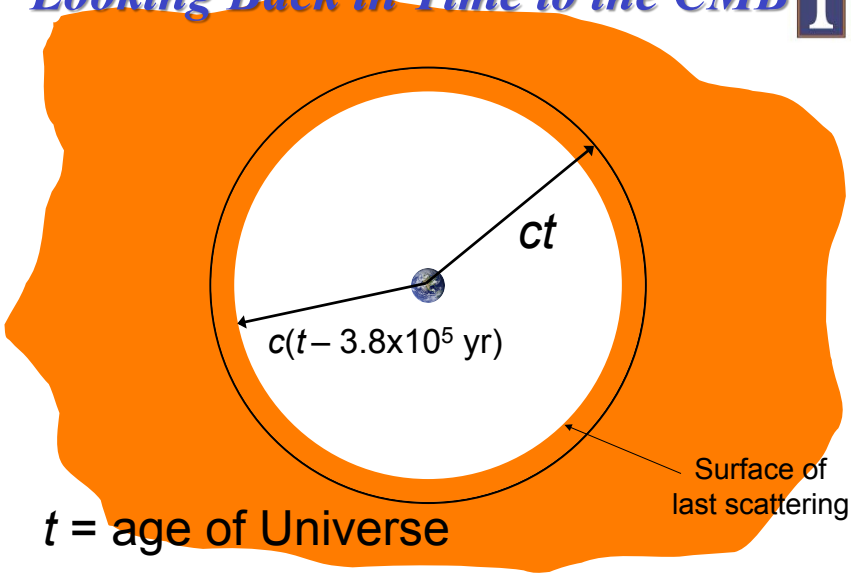


Question

How did Hydrogen first appear in the Universe?

a) When the Universe cooled and quarks combined to form the first protons, eventually gaining an electron.
b) When the Universe cooled and the melted protons reformed, eventually gaining an electron.
c) When the Universe cooled and the antimatter turned into matter, eventually gaining an electron.
d) When the Universe cooled and the hydrogen atoms fused into helium atoms, eventually gaining an electron.
e) They always existed.

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 380,000 years after the Big Bang.