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?

ET: Astronomy 230

Section 1– MWF 1400-1450

134 Astronomy Building

This Class (Lecture 4):

The Early Galaxy and the First Stars

Next Class:

From Atoms to Molecules to Clouds

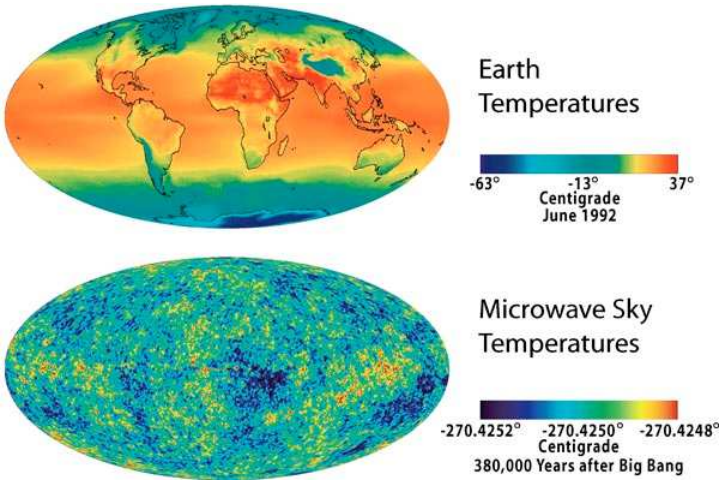
HW1 due on Friday.

Music: *Across the Universe* – Beatles

Outline

- Big Bang Nucleosynthesis
- Cooling into normal stuff.
- The seeds of galaxies.
- What is the probable fate of the Universe?

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



THE VERY EARLY UNIVERSE

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

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!

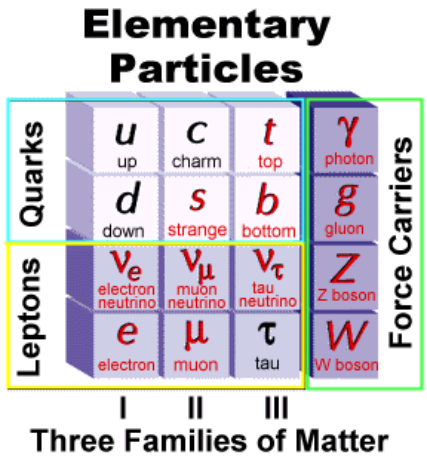
Probes conditions in Universe at 10^{-12} s

Universe was 10^{12} K hot!

…but also…

"The Universe is the poor man's accelerator"

Probes conditions inaccessible at laboratories



4 Fundamental Forces

- Gravity
- Electromagnetic
- Strong Nuclear
- Weak Nuclear

Gravity

- As described by Newton
- The weakest of the forces, yet it is the dominant force in the Universe for shaping the large scale structure of galaxies, stars, etc.
- Only purely attractive force
- Arguably the least understood force
- Infinite range

Electromagnetic

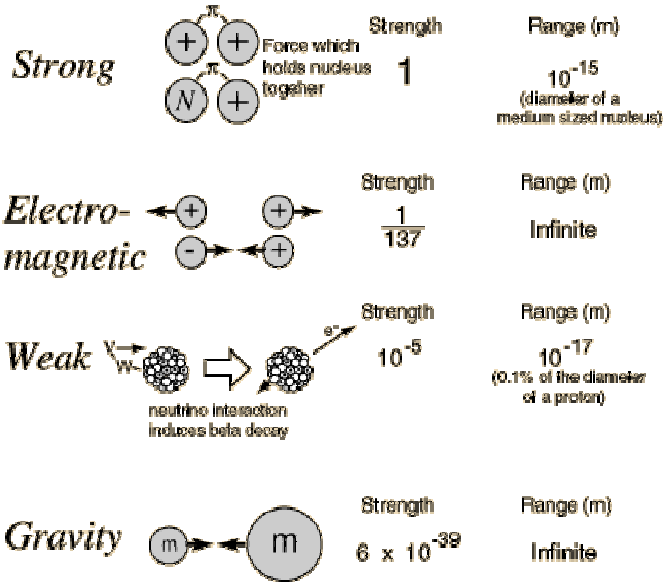
- Similar to the gravitation force (inverse square law)
- Electric and Magnetic fields
- Both attractive and repulsive force
- Only acts on charges particles
- Responsible for all electric and magnetic phenomena we observe— includes light.
- Infinite range

Strong Nuclear

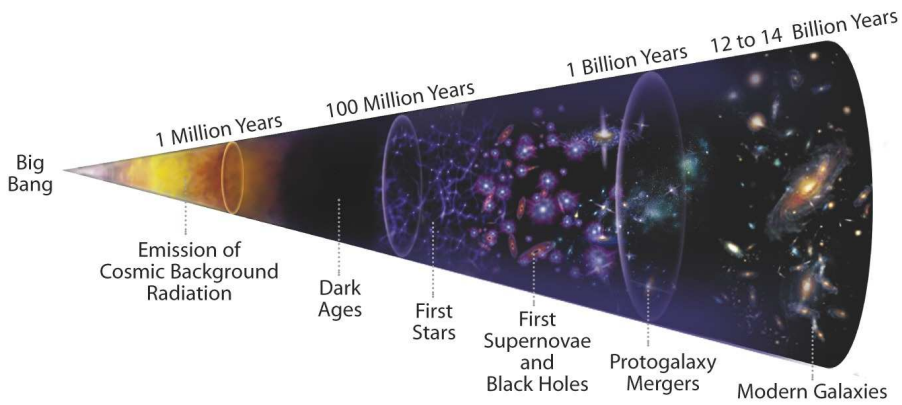
- The strongest of the 4 forces
- The force which holds an atom's nucleus together, in spite of the repulsion between the protons.
- Does not depend on charge
- Not an inverse square law– very short range.

Weak Nuclear

- Moderates certain kinds of nuclear decays such as the neutron decay
- The most common particle which interacts only via the Weak Force is the *neutrino*
- Very short range



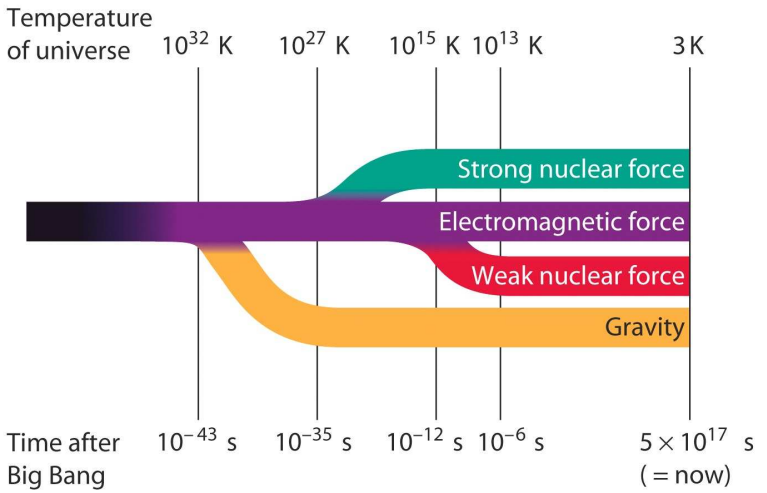
A Brief History of Time



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

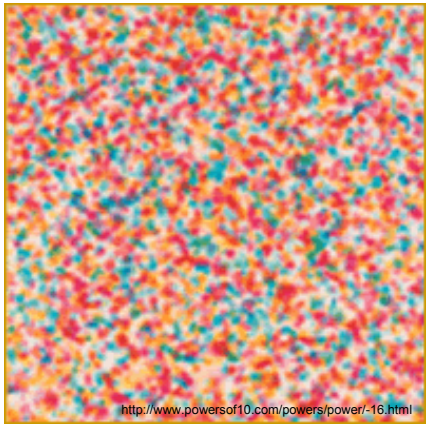
- Incredibly hot (more that 10^{32} K)
- Our current hypothesis – only one force in nature
  - The four forces were unified
  - Remains to be proven, as the theories we use to describe nature don't work in this era
- At the end of this era, gravity became a separate force
- Want a Nobel Prize? Develop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

Dis-Unification of the Forces



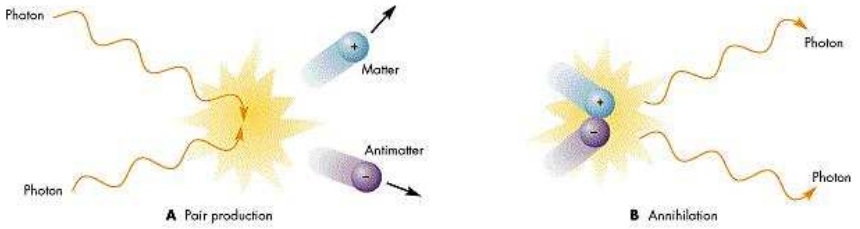
The GUT Era (until 10^{-35} sec)

- GUT = "Grand Unified Theory"
- Two forces
  - Gravity
  - Strong/weak/electro-magnetic
- Sea of free quarks (and anti-quarks) + photons + other basic particles
- Random fluctuations in density



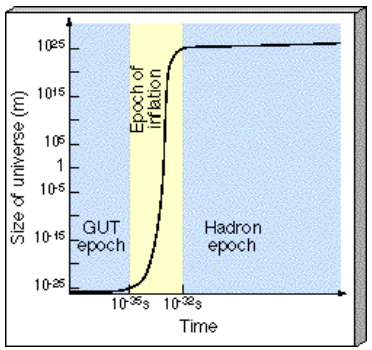
Matter and Anti-Matter

- 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



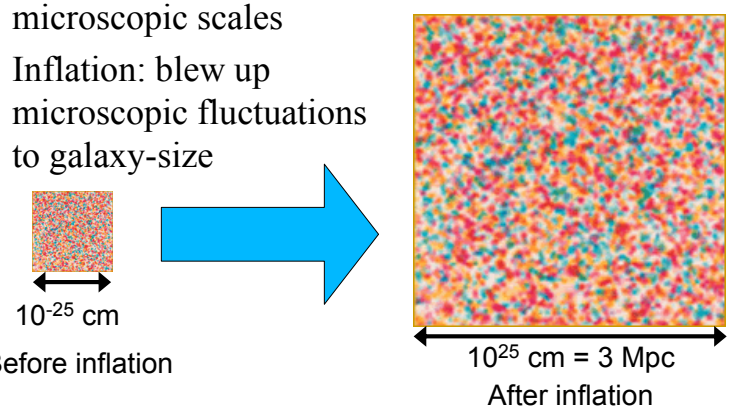
Inflation (10^{-35} to 10^{-32} sec)

- 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!



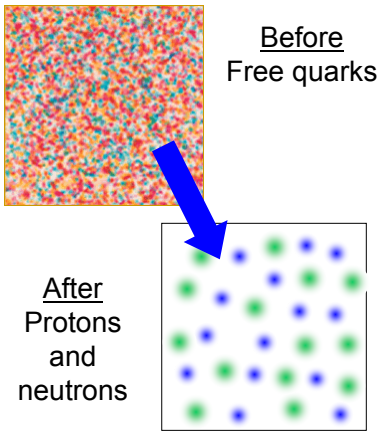
Origin of the CMB Fluctuations

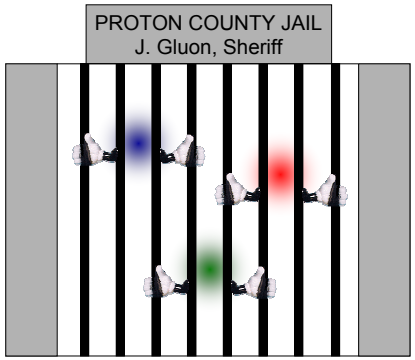
- Early Universe: a sea of particles & energy
- Density was constantly fluctuating on microscopic scales
- Inflation: blew up microscopic fluctuations to galaxy-size



Quark Confinement

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





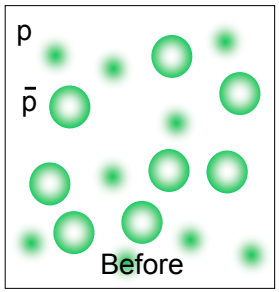
10^{31} years to life
Little chance of parole

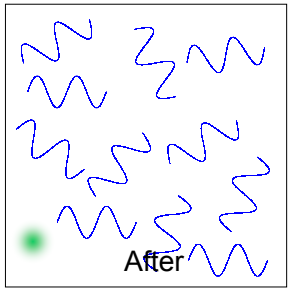
The Universe is Made of Matter

- 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?

Annihilation of the Anti-matter

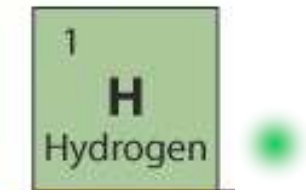
- 10^{-4} seconds:
  - Temperature dropped below the level at which photons have enough energy to create proton-anti-proton pairs
  - Remaining pairs annihilated → radiation
  - 1 proton in 10^9 had no partner! That's us





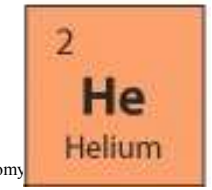
Big Bang Nucleosynthesis

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.

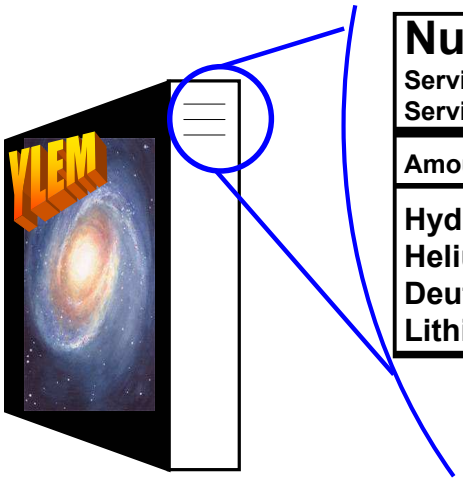


(a proton)

Also: Deuterium



End Result:
Big Bang Correctly Predicts Abundances



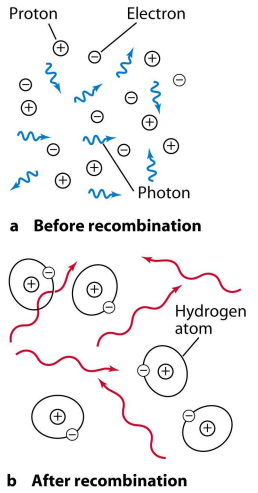
Nutrition Facts
Serving Size 1 g
Servings Per Universe many many

Amount Per Serving

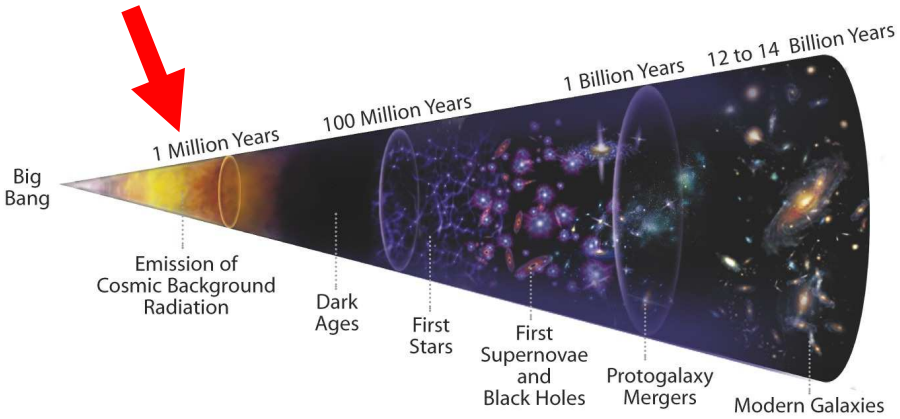
Hydrogen	**0.75 g**
Helium	**0.25 g**
Deuterium	**10^{-4} g**
Lithium, etc.	**10^{-10} g**

Era of Recombination

- In the early Universe, photons were energetic enough to keep atoms ionized
  - protons and electrons couldn't make neutral hydrogen atoms
- After 500,000 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!



Origin of the CMB

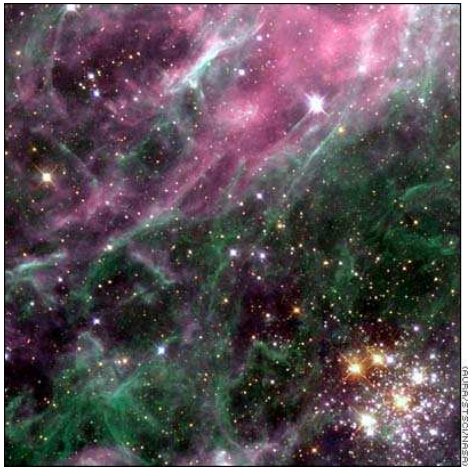


- After recombination came a period known as the Dark Ages
  - 500,000 to 100 million years
  - No light comes to us from this period
- Matter consists of warm clouds of hydrogen and helium
  - Too hot for star formation to occur
  - Gravity slowing drawing clouds together into bigger and bigger clumps

http://www.darkages.com/

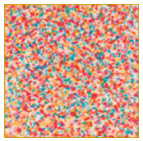
The First Stars

- We think the first stars began to form after about 200 million years
- Proto-galactic clouds are slowly collapsing – no galaxies yet

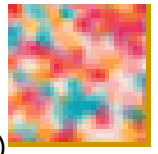


The Beginnings of Galaxies

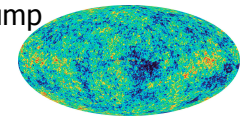
Quantum fluctuations during GUT era (before 10^{-35} s)



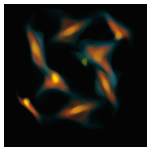
Inflation stretches fluctuations to galaxy size (before 10^{-32} s)

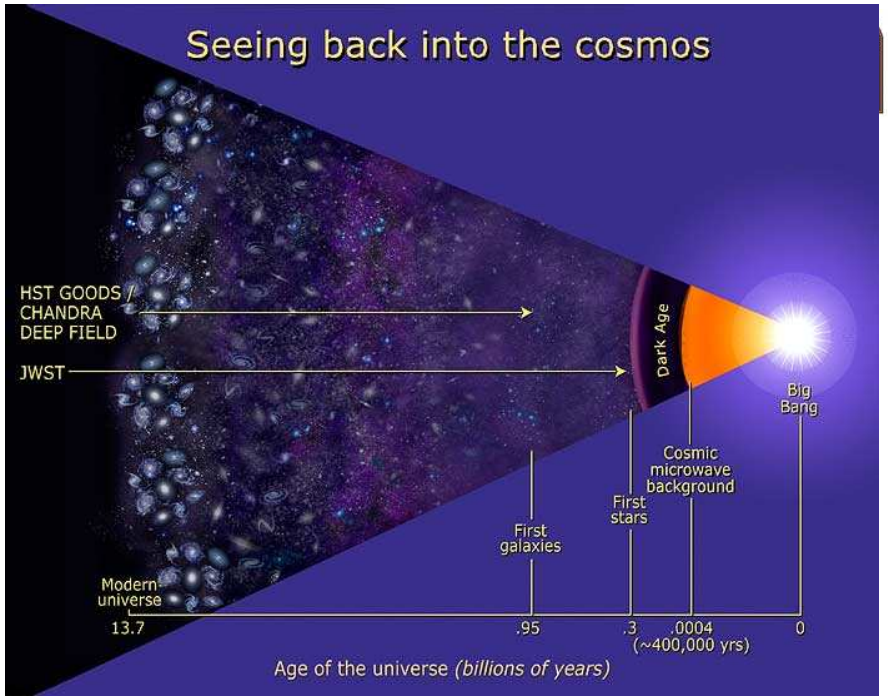


Before recombination, particles moving too fast to clump



After recombination, gravity of denser regions draws particles together

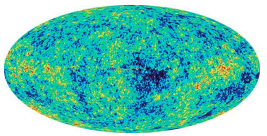




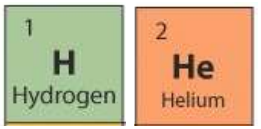
From the Home Office in Urbana, IL

Top 3 Reasons We Believe in the Big Bang

1. Cosmic Microwave Background
   - Big Bang working at about 500,000 yrs
   - Tiny fluctuations: "seeds" of galaxies



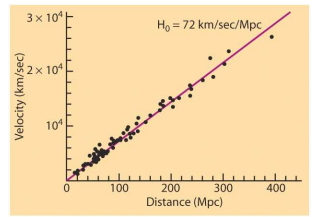
2. Big Bang Nucleosynthesis
   - H and (almost all) He come from the Big Bang
   - Big Bang working at 1 sec



3. The Hubble Law: $v=H_0 d$

   + Einstein's General Relativity

   = Expanding Universe with an age of 13.7 billion yrs



What is the fate of the Universe?

Fire and Ice

Some say the world will end in fire,
Some say in ice.
From what I've tasted of desire
I hold with those who favor fire.
But if it had to perish twice,
I think I know enough of hate
To say that for destruction ice
Is also great
And would suffice.

-- Robert Frost

What is the Universe's Fate?

Today: Universe is expanding. What do you expect to happen next?

Competition: gravity vs inertia

Compare: Pop fly and rocket!

- Quantitative question
- Launch speed vs speed to escape Earth

or

?

What is the Universe's Fate?

For Universe it is still gravity vs speed.

- Gravity acts on mass of galaxies (pulling back)
- The speed is the speed of expansion

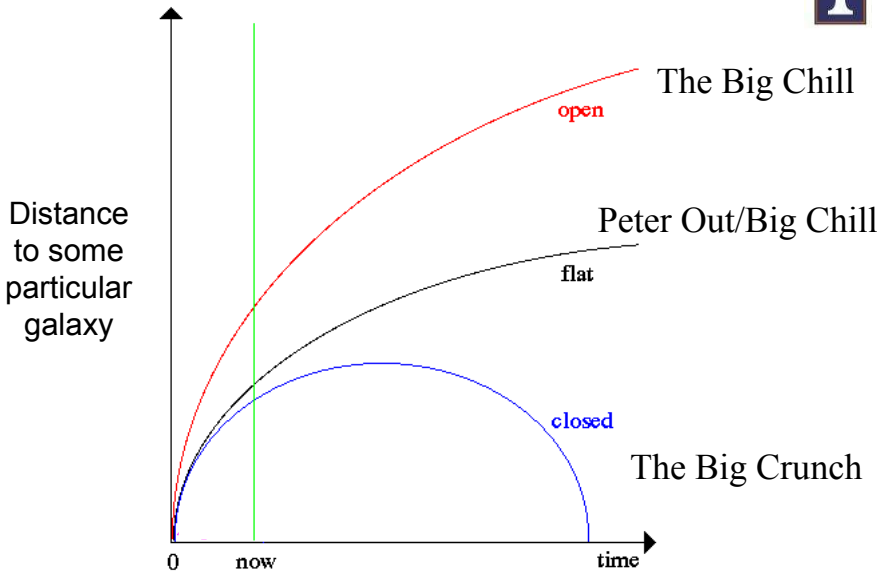
or

Both are observable!

Our fate is a **quantitative** question :

- **If our mass is small enough we expand forever.**
- **If our mass is large enough expansion halts, and we collapse.**

What kind of Universe do we live in?



Big Chill/Big Crunch

- Less mass: An open or flat Universe will end in a **Big Chill**:
  - Galaxies exhaust their gas supply
  - No more new stars
  - Old stars eventually die, leaving only dust and stellar corpses
- More mass: A closed Universe will end in a **Big Crunch**:
  - Expansion will stop, and the Universe will re-collapse
  - Ends as it began, incredibly hot and dense

How Much Do We Weigh?

% of critical mass

22% Dark matter

Needed to explain:
galaxy rotation curves
clusters of galaxies

4.5% Ordinary matter

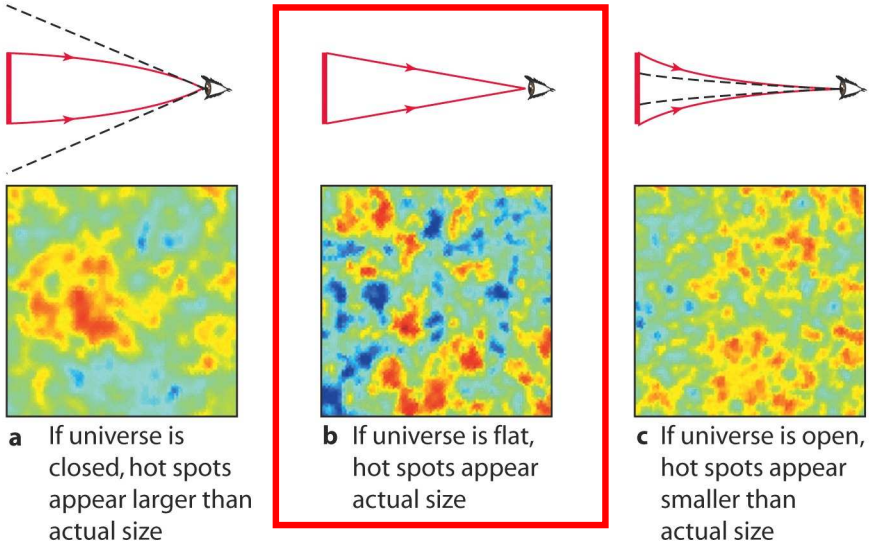
Made of protons, neutrons, and electrons

<1.5% Neutrinos

28% Total Not enough to close the Universe

CMB Measurements

Universe is Flat!!!!



a If universe is closed, hot spots appear larger than actual size

b If universe is flat, hot spots appear actual size

c If universe is open, hot spots appear smaller than actual size

Peter Out/ Big Chill

- The Universe will just barely expand forever, getting cooler and cooler.
- If all of the mass, dark+regular, isn't enough, **then what's up**?
- The fate of the Universe is really dependent on the amount of matter and energy in the Universe → $E = mc^2$
- So, a new type of energy called Dark Energy (repulsive gravity and not related to Dark Matter) exists. The dark energy is dominating the fate of the Universe.
- 70% of the Universe is this dark energy.
- Einstein's biggest blunder might have been correct after all.

Dark Energy

- The matter census isn't enough to be flat
- So, a new type of energy called ***dark energy*** exists
  - Not related to dark matter
  - Acts as repulsive gravity
- Dark energy is actually *accelerating* the expansion of the Universe!