Astronomy 330:

Extraterrestrial Life

<u>This class (Lecture 5):</u>

Big Bang Theory

<u>Next Class:</u>

Fate of the Universe

Presentation Synopsis due Sunday night.

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

Big Bang

- We spent the last class discussing the Big Bang.
- In small groups, write a 4-5 sentence explanation of the Big Bang to a non-science major friend.
  - What is the main idea? State some of the important facts.

Are we alone?

Life as we know it requires **CHON**

Carbon **H**ydrogen **O**xygen **N**itrogen

Where did H come from?

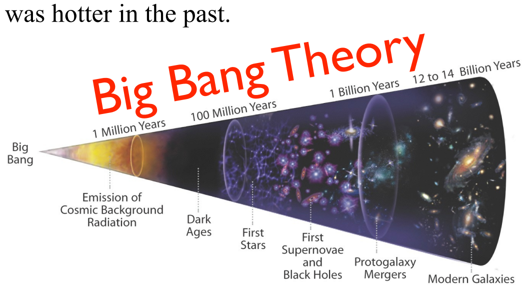
Where did H come from? It is the simplest element— 1 proton and 1 electron. Must be easy. Right?

What does this mean?

1) Universe is expanding.

2) Universe was more dense in the past.

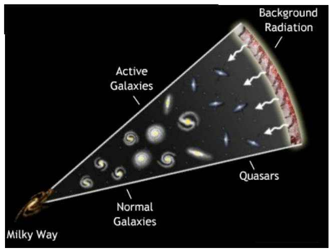
3) Universe was hotter in the past.



Evidence supports!

What is the history of the Universe according to the Big Bang theory?

- Cannot begin the history of the Big Bang at time zero
  - Physics not understood
- Shortly after the Big Bang
  - Observable Universe was smaller than an atomic nucleus
  - Compact Universe = freaky high density, freaky high temperature



At the moment of the Big Bang. Our current observable universe was smaller than an atomic nucleus. Compact universe = high density, high temperature. Universe cooled as it expanded. Cosmologists cannot begin their history of the big bang at time zero. No one understands the physics of matter and energy under such extreme conditions. Nevertheless, they can come amazingly close.

Inner/Outer Space

Fermilab is a telescope!

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

Universe was 10^{12} K hot!

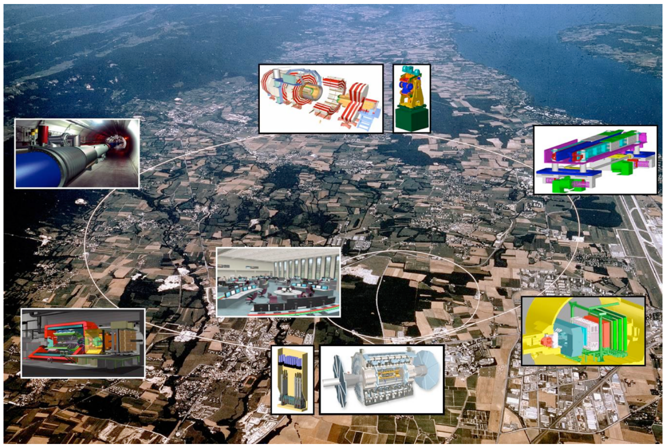
…but also…

"The Universe is the poor man's accelerator"

Probes conditions inaccessible at laboratories

First: Background Primer
- Basic Particles
- Matter & Antimatter

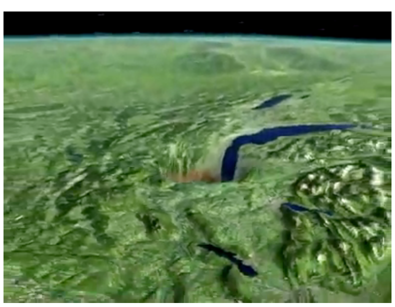
LHC



Credit: CERN

Improve our understanding of particle physics at higher energies.

LHC Problems? NO.

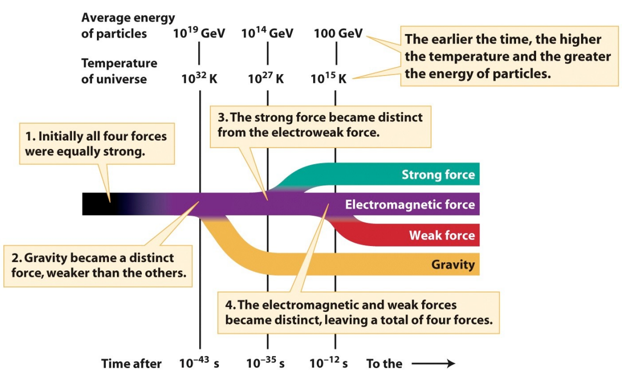


This is what would happen if a micro-black hole formed at CERN. This is NOT thought to be an issue, but still fun movie.

The LHC

Credit Daily Show April 2009

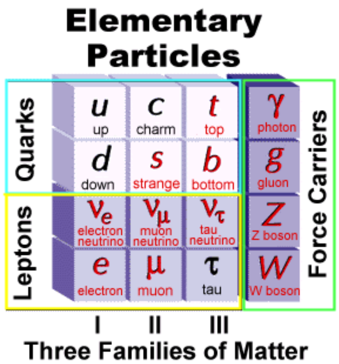
Fundamental Forces



Credit: Universe, 8e, Addison Wesley

Basic Particles

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



Particle Review

From the Standard Model of Particle Physics: Quantum Chromodynamics

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

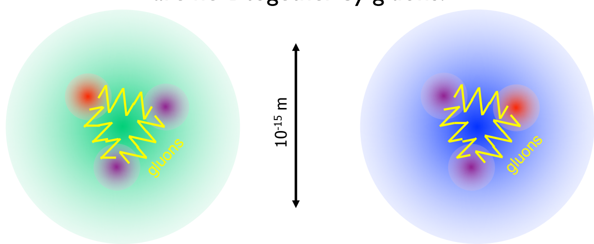
Flavor	Mass GeV/c^2	Electric charge	Three Families of Matter
ν_e electron neutrino	$<1\times10^{-8}$	0	I
e electron	0.000511	–1	I
ν_μ muon neutrino	<0.0002	0	II
μ muon	0.106	–1	II
ν_τ tau neutrino	<0.02	0	III
τ tau	1.7771	–1	III

Quarks spin = 1/2

Flavor	Approx. Mass GeV/c^2	Electric charge	Three Families of Matter
u up	0.003	2/3	I
d down	0.006	–1/3	I
c charm	1.3	2/3	II
s strange	0.1	–1/3	II
t top	175	2/3	III
b bottom	4.3	–1/3	III

Quarks

Basic particles like protons and neutrons (also known as *Hadrons*) are held together by gluons.



$up + up + down = proton$

$$\frac{2}{3} + \frac{2}{3} - \frac{1}{3} = 1$$

$up + down + down = neutron$

$$\frac{2}{3} - \frac{1}{3} - \frac{1}{3} = 0$$

Question

Quarks are

a) composed of protons and neutrons.

b) alien technology.

c) fundamental particles that make up normal baryonic matter.

d) antimatter particles that survive as relics of the Big Bang

e) quantum gravity fluctuations.

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E

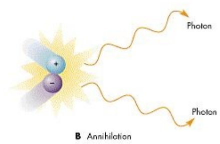
Matter & Antimatter

Every particle has an antiparticle.

quark ⟷ antiquark   electron ⟷ positron

antistar ⟷ star

When matter & antimatter combine: ***Annihilation***!

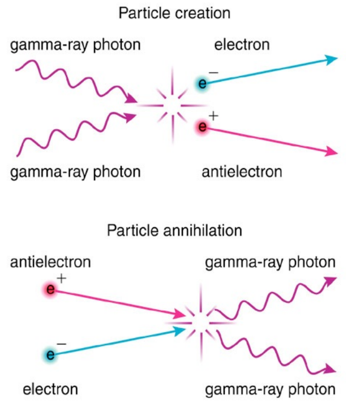


Is Universe made of Matter or Antimatter?

Credit: Discovery Channel

https://www.youtube.com/watch?x-yt-cl=85027636&x-yt-ts=1422503916&v=FWYa8sQl6-I

Thermal Equilibrium



Credit: Universe, 8e, Addison Wesley

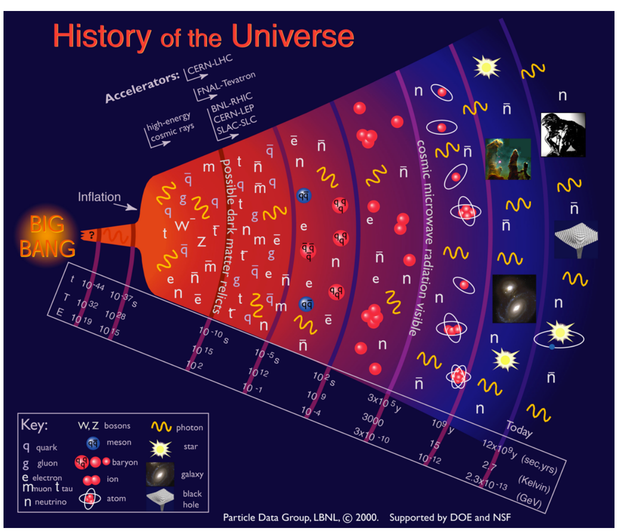
Early universe was full of particles and radiation because of its high temperature

$$E = mc^2$$

Photons converted into particle-antiparticle pairs and vice-versa

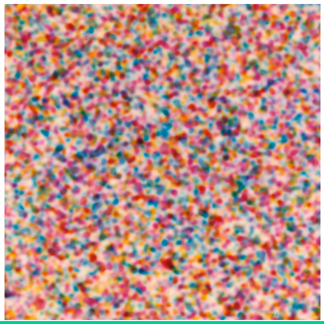
When light with enough energy interact, can produce matter & antimatter pairs: Pair Production!

Early Universe so hot, this was happening with annihilation— in equal amounts.



The Universe at 0.0000001 seconds

- Filled with high-energy gamma-ray photons and exotic particles
- Average temperature well over **1 trillion K** (10^{12} K)!
- Average density is nearly that of an atomic nucleus

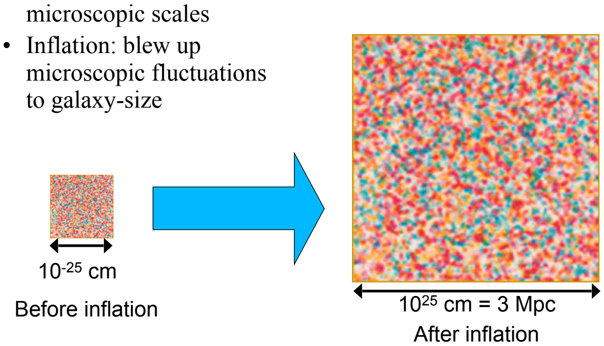


Early universe was a 'soup' of energetic particles and radiation

We don't know how the Universe began, but we do know the conditions shortly after. Note, matter and energy.

Origin of the CMB Fluctuations

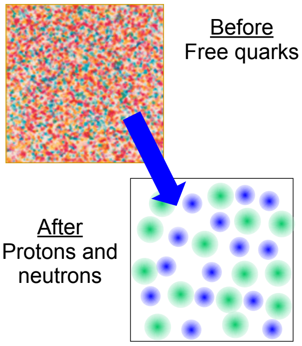
- Early Universe: a sea of particles & energy
- Density was constantly fluctuating on microscopic scales
- Inflation: blew up microscopic fluctuations to galaxy-size



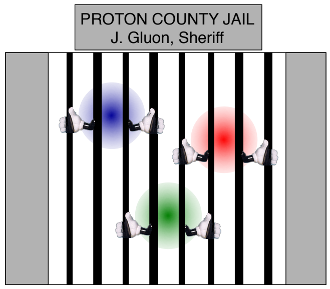
Quark Confinement

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

<u>Before</u>
Free quarks



<u>After</u>
Protons and neutrons



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

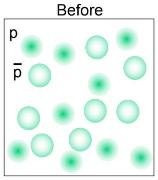
End of Antimatter

10^{-4} seconds

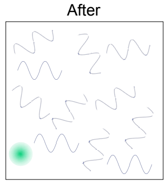
Universe cools creating proton-antiproton pairs.

Remaining pairs annihilate → radiation

Before



After

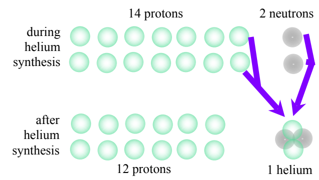


Slight asymmetry: 1 proton in 10^9, leading to all matter in Universe

At 0.0001 s, universe cools below 10 K
Photons no longer have the energy to create particle pairs
Remaining pairs annihilated
But, there was a slight excess of normal matter
For every 1 billion antiprotons there was 1 billion and 1 regular protons-- that left over proton is you
So, we live in a world of matter

3 minutes old: The first elements!

- Temperature ~ 10^9 K
- Fusion only lasts a few minutes due to expansion - Quick Fireball!
- Ratio of hydrogen to helium: 75% to 25%

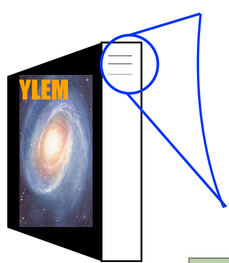


As the Universe cools, some protons and neutrons fuse to form helium nuclei

By the time the universe was 3 minutes old, it had become so cool that most nuclear reactions had stopped. About 25 percent of the mass was in the form of helium nuclei.The rest was in the form of hydrogen nuclei (protons). Astronomers can calculate that the big bang produced a tiny amount of lithium but no elements heavier than that. Heavier elements were built by nuclear processes inside later generations of massive stars.

Still only ionized atoms— i.e. without electrons.

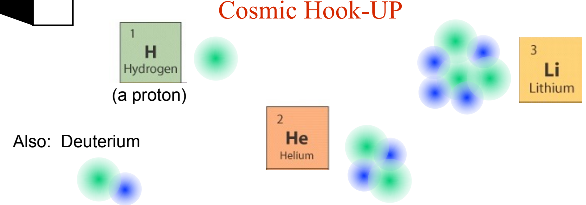
BBN



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

Cosmic Hook-UP



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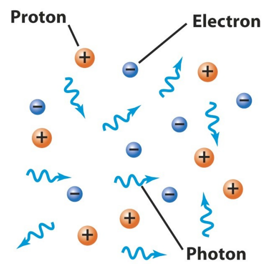
This theory completely describes the abundances of elements observed. This theory is called the Big Bang Nucleosynthesis theory.

Radiation and Matter in the Early Universe

- Young universe was hot so gas was *ionized*
- Photons and matter interact continuously with each other and cool together as the universe expands



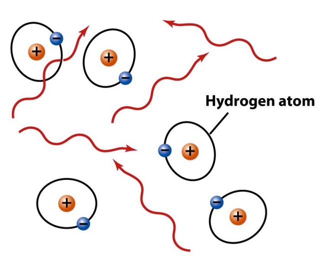
The young Universe was filled with hot, dense, *ionized* gas

Free atomic nuclei and electrons: Ionized: The electrons were not attached to atomic nuclei

Free electrons interact with photons so easily that a photon could not travel very far before it encountered an electron and was deflected. Matter could not clump together because the intense sea of photons smoothed the gas out. As the young universe expanded, it went through three important changes.

380,000 years old: The first atoms!

- The universe cools to ~3,000 K
- Hydrogen & helium nuclei capture electrons & form neutral ***atoms***
- This neutral gas is transparent to light



After atoms formed, the Universe was filled with hot, dense, *neutral* gas

As the density decreased and the falling temperature of the universe reached 3,000 K, protons were able to capture and hold free electrons to form neutral hydrogen.This process is called recombination—although ‘combination’ (for the first time) would be more accurate. As the free electrons were gobbled up into atoms, they could no longer deflect photons.The photons could travel easily through the gas. So, the gas became transparent. Also, the photons retained the blackbody temperature of 3,000 K that the gas and photons together had at the time of recombination.

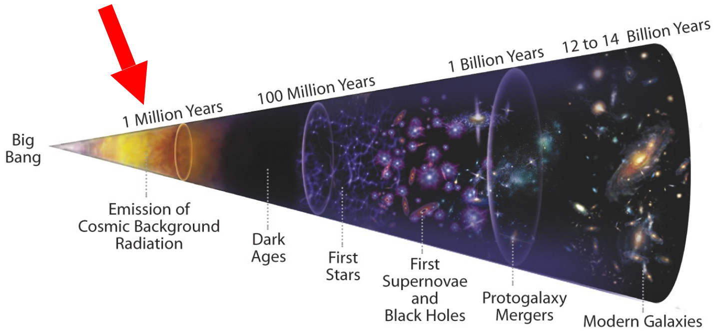
Before this time, photons could ionize Hydrogen atoms.

Expansion of space (redshift) lowered photon energy.

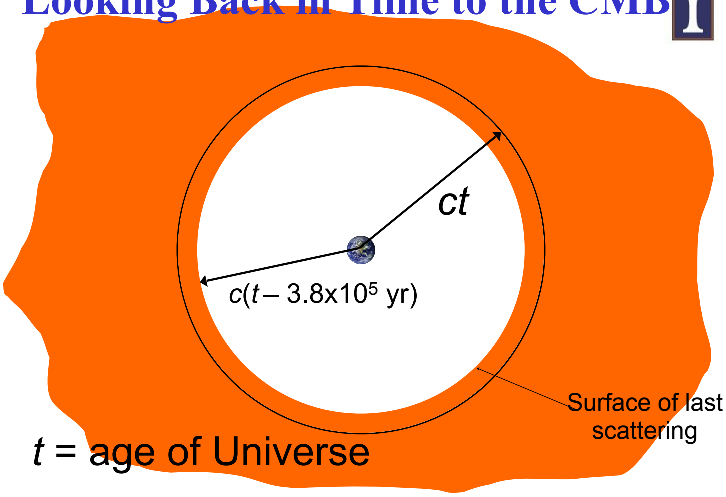
Universe becomes transparent, photons free-stream.

The first H atoms in the Universe!

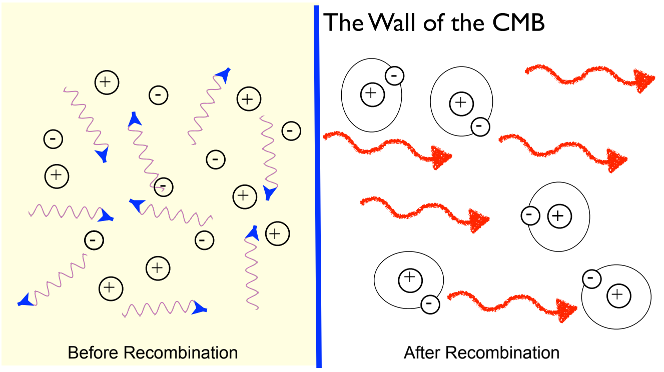
Origin of the CMB



Looking Back in Time to the CMB



Looking Back in Time to the CMB



The CMB is light from the Era of Recombination!

The CMB comes from the era of recombination. Before that, photons were stuck ionizing any hydrogen atoms that formed and they could not travel very far, but when the Universe cooled down enough, the photons did not have enough energy to ionize hydrogen and the Universe became transparent to the light, allowing the light to travel all the way to us. This is the CMB.

Why is light from the Big Bang observed in microwaves?

Expansion of the universe redshifted the light to *~1100 times longer wavelengths* - microwaves!

Question

B

How did Hydrogen originate in the Universe?

a) It has always existed.

b) As the Universe expanded and cooled, quarks formed protons, which eventually gained an electron.

c) As the Universe expanded and cooled, matter and antimatter annihilated leaving behind Hydrogen.

d) As the Universe expanded, gamma rays interacted with Helium, which broke apart into Hydrogen atoms.

e) Aliens.

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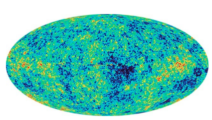
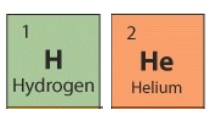
From the Home Office in Urbana, IL
Top 3 Reasons We Believe in the Big Bang

1. Cosmic Microwave Background
   - Big Bang working at about 380,000 yrs
   - Tiny fluctuations: “seeds” of galaxies



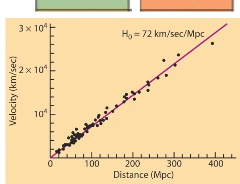
2. Big Bang Nucleosynthesis
   - H and (almost all) He come from the Big Bang
   - Big Bang working at 1 sec



3. Hubble’s Law: $v=H_0d$

+ Einstein’s General Relativity

= Expanding Universe with an age of 13.8 billion yrs



One of the most successful scientific theories of all time!

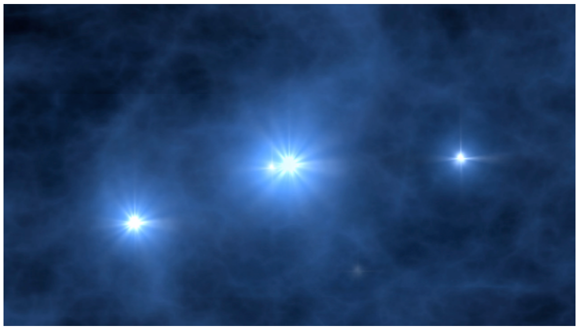
Big Bang Model

It's like, totally awesome, dude!

- After recombination came a period known as the Dark Ages
  - 380,000 to 400 million years
  - No light yet detected 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
  - Proto-galaxies

http://www.darkages.com/

400 million years old: The first stars!



The dark age ended as the first stars began to form

Gravity draws gas in, forming the first stars after 400 million years. The gas from which these first stars formed contained almost no elements heavier than hydrogen and helium. Mathematical models show that the first stars formed from this gas would have been very massive, very luminous, and very short-lived. Remember mostly hydrogen gas with very few metals. These stars gave the Universe it first supply of heavy elements.

Question

A planet forms around one of the first stars in the Universe, which of the following is the most correct?

a) It will be a rocky planet.
b) It will be mostly made from hydrogen.
c) The life that forms on this planet will be very alien.
d) It will be a reddish-blue color.
e) It will be made in the outer reaches of the Galaxy.

The Universe: Timeline

- Big Bang: 13.7 billion years ago
- GUT era: $+10^{-35}$ second, energy and quarks
- Quark confinement: 10^{-32} to 10^{-6} seconds, protons and neutrons form
- Matter vs. antimatter: 10^{-6} seconds, matter wins
- Big Bang Nucleosynthesis: 10^{-4} seconds to 3 mins, He and some other nuclei form.
- Era of Recombination: 380,000 years. Universe becomes transparent, CMB
- Dark Ages: 380,000 to 400 million years, gravity works on stuff
- Stars: 400 million years, first stars form, protogalaxies

What is the fate of the Universe?

Fate of the Universe

or

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

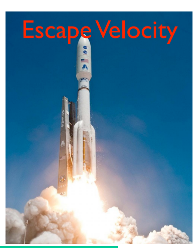
Fate of the Universe

Hubble showed Universe is expanding today.

Fate determined by
gravity versus inertia!

?

or



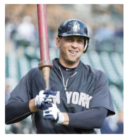
Note chemical assistance!

Which one do you expect to fall back to Earth and why?

Fate of the Universe

Gravity *pulls* galaxies together

Expansion *pushes* them apart



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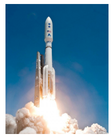


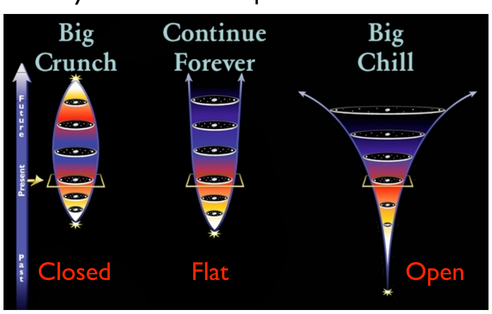
mass → Expansion *wins!*

mass → Gravity *wins!*

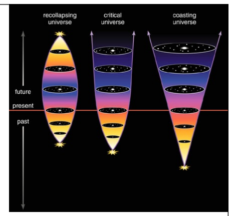
Fate of the Universe

mass → Gravity *wins!*

mass → Expansion *wins!*

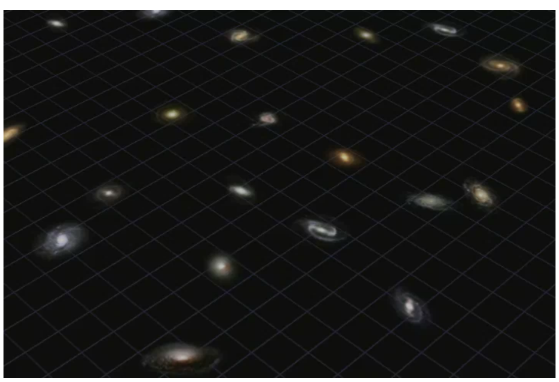


Big Chill/Big Crunch



- **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

Recollapsing Universe

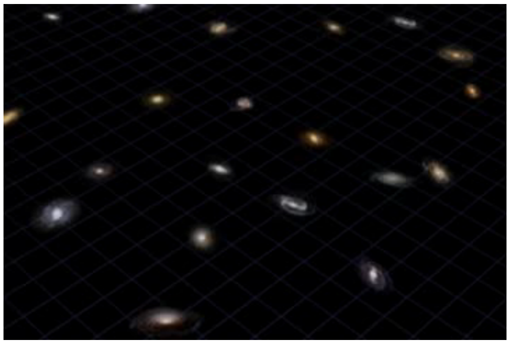


If there is enough matter in the Universe to halt the expansion, it will eventually recollapse

a contracting universe would become increasingly dense. Eventually all matter would collapse into black holes, which would then coalesce producing a unified black hole or Big Crunch singularity.

Click to begin movie

Expanding Forever



If there is not enough matter in the Universe to halt the expansion, it will continue forever

The galaxies will get farther and farther apart.They will use up their gas and dust making stars.Ultimately, the stars will all die.Each galaxy will be isolated, burnt out, dark, and alone.

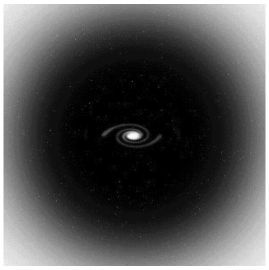
Click to begin movie

Weighing the Universe?

How Much Does the Universe Weigh?

- The first major component is luminous matter.
- The stuff (most of which will talk about soon)
  - You
  - Stars
  - Planets
  - Gas
  - Dust
  - Molecular clouds
  - White Dwarfs
  - Etc.

And Dark Matter

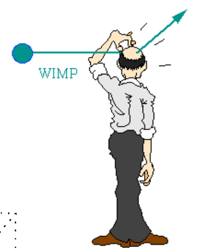


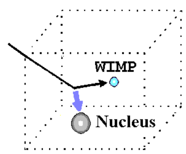
- The unseen mass in our Galaxy!
- Needed to explain stellar orbits.
- The dark matter in the Galaxy is in greatly extended halo
  - Up to 90% of the Galaxy's mass is dark matter!
- Most of our Milky Way is Dark Matter
  - We can't see it (only interacts via gravity)
  - We aren't sure what it is, but it is much more common than "normal matter"

Dark Matter

- Dark matter is likely streaming through us right now!
- Probably some heavy exotic particle created during the Big Bang. (Weakly Interacting Massive Particle–WIMPs?).
- Recent suggestion of a detection. Stay tuned!

How to search for WIMPs?

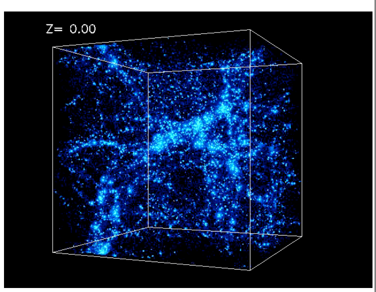




http://www.shef.ac.uk/physics/research/pa/DM-introduction-0397.html

What is the role of dark matter in galaxy formation?

- Gravity of dark matter draws in gas
- Creates a "lumpy" distribution, proto-galactic clouds
- Without dark matter, models show galaxies don't form
- No dark matter = no galaxies = no us!



Over time, denser regions draw in more and more matter

Models show that gravity of dark matter pulls mass into denser regions. As the universe expands (note the increasing size of the box as time moves forward), that the matter in the universe grows "lumpier". Even as the whole universe spreads out, the regions that had higher concentrations of dark matter continue to grow denser. The gravity of dark matter seems to be what drew gas together into protogalactic clouds, initiating the process of galaxy formation

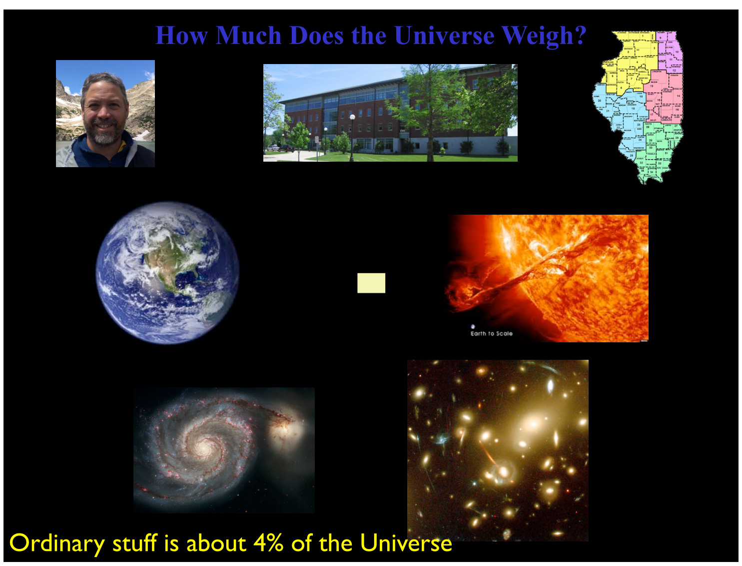
How Much Do We Weigh?

% of mass for
closed Universe

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

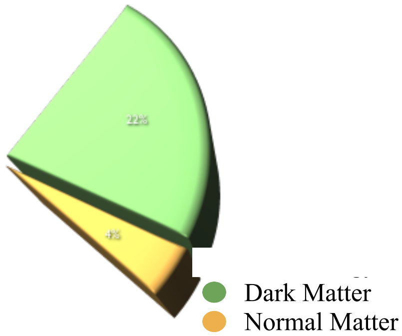
28%	Total

Not enough to close the Universe



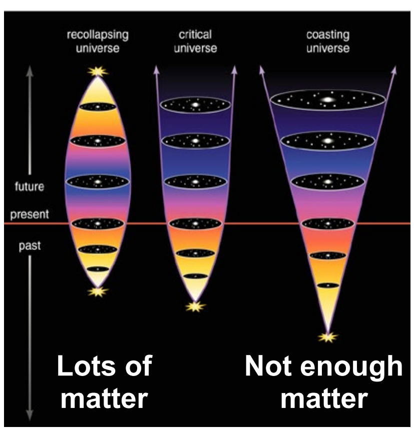
Everything we see and feel is approximately 4% of everything that exists in the Universe. You thought you were more important?

Dark Matter



Is there enough matter?

- In other words, the Universe does not weigh enough to bring the Universe back on itself
- In our analogy, the rocket keeps going.



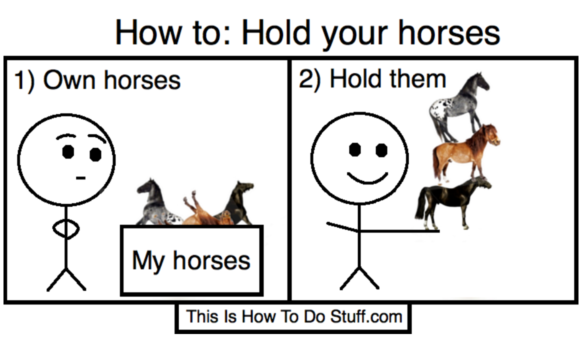
Critical density is the density needed

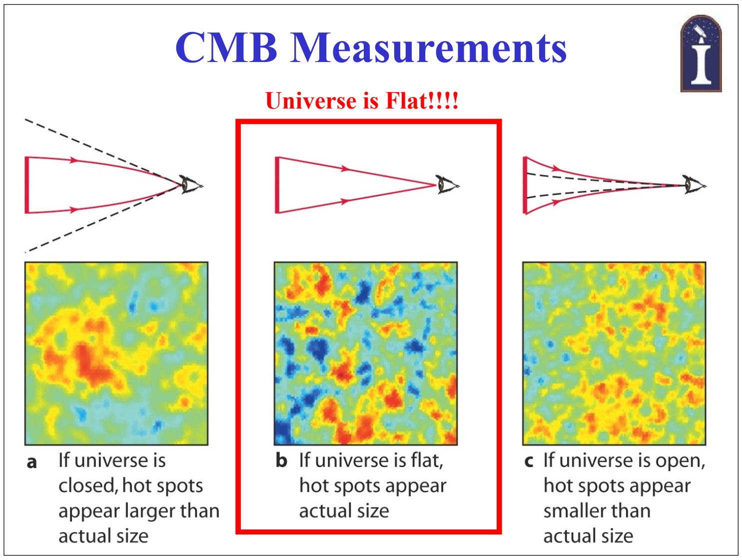
Fate of the Universe

Open Universe

?

Wait a minute…





Let’s check Hubble’s Law. We would expect a certain behavior.