Astronomy 210

The Last Class (Lecture 41):

The End and the Beginning

Review session:
May 6th or May 9th?

Final

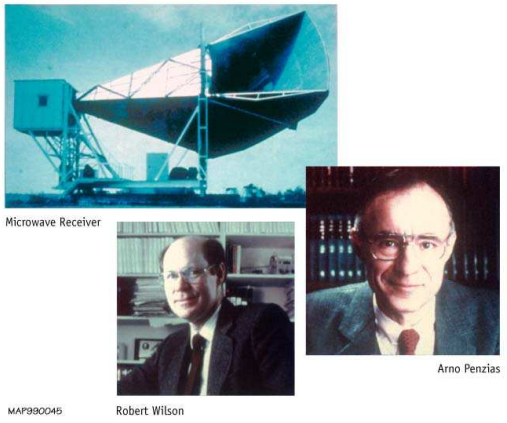
- In this room at 1:30pm-4:30pm on May 10th.
- Designed to be 2 hours long
- 1st half is just like the other 2 hour exams on the material after hour exam #2.
- 2nd half is review of the entire semester.
- You may bring a single sheet of paper with notes.
- Total exam will have 210 points, but graded out of 200 points.

Outline

- Cosmic Microwave Background
- How Illinois is probing the early Universe
- A Brief History of Time
- The Rest of the Beginning of Time
- What is the fate of the Universe?
- What is Dark Energy?

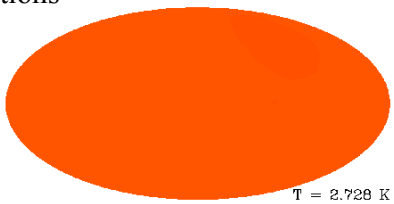
The Early Universe was HOT*!*

- 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.
- First detected by Robert Wilson and Arno Penzias.



Small Scale Variations

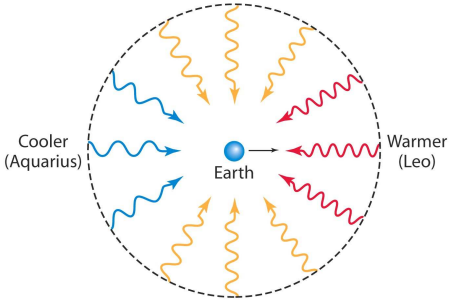
- Although the CMB is smooth, there are small scale variations
- Largest variations are due to motions
  - Motions of the Sun around the Galaxy
  - Motions of the Galaxy in the Local Group
  - Motions of the Local Group in our supercluster

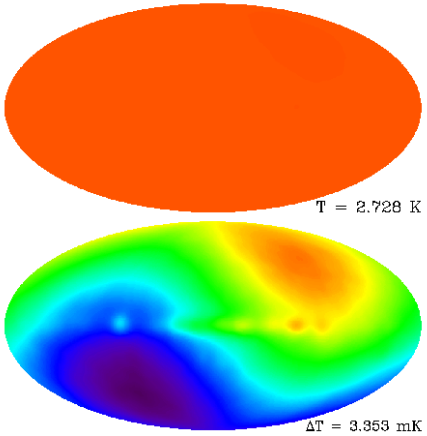


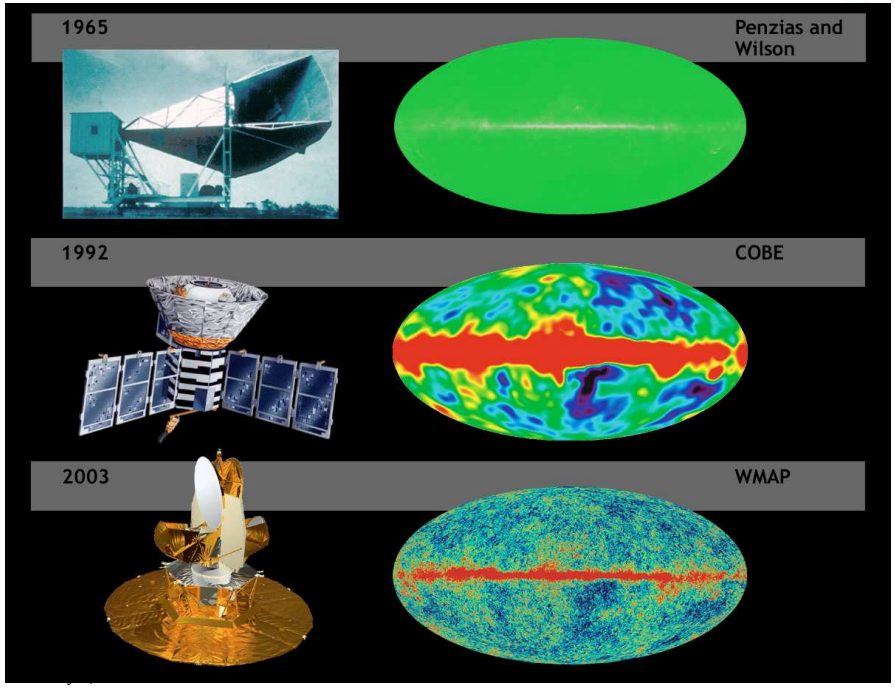
- There are also Galactic sources of microwave radiation
- First, we have to remove these variations…
  - What is left is cosmological - from the Big Bang

Anisotropy

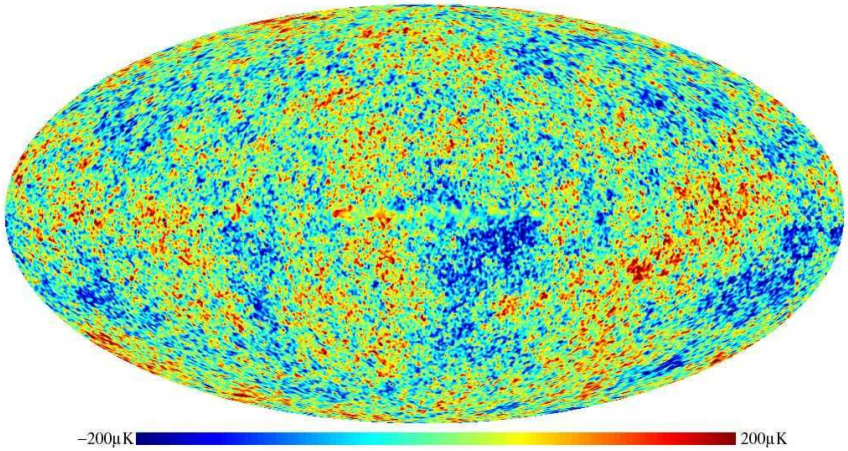
- Small scale variation, due to our movement with respect to the background.
- We are moving about 600 km/s or 1.3 million mph.
- Remove this and MW Galaxy component.



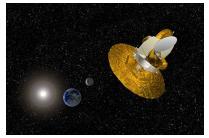




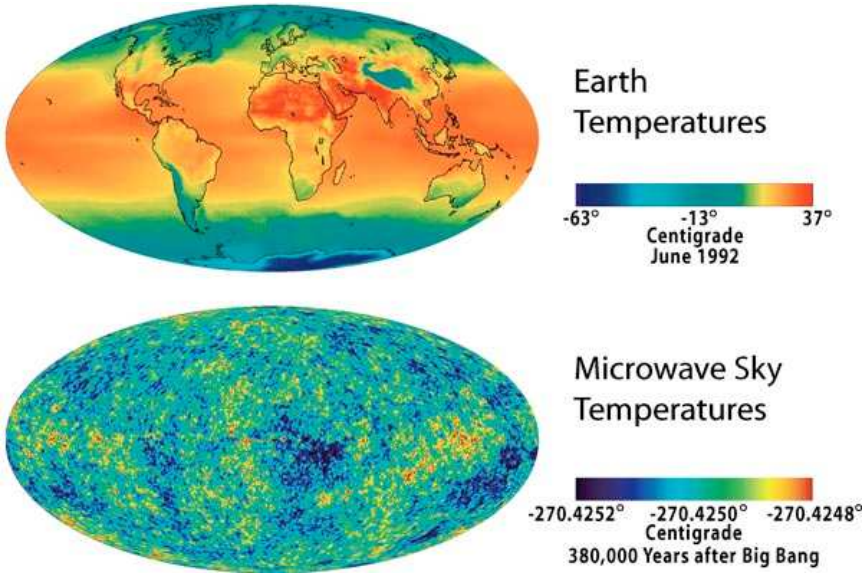
WMAP Results



All sky map from 2003. More sensitive and higher resolution than Cobe. Variation less than 1 part in 100,000.

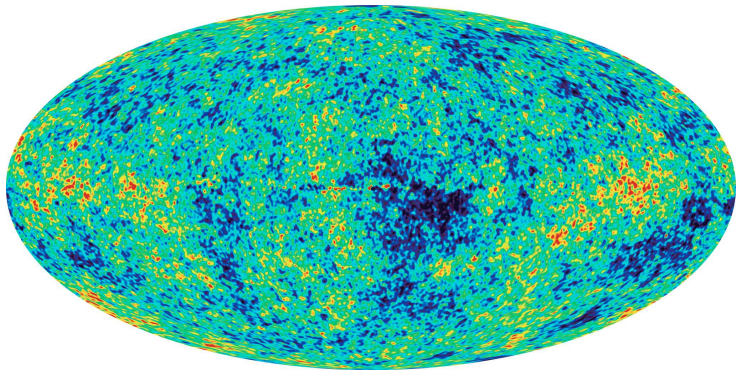


WMAP took a "baby picture" of the Universe– only 400000 yrs old.



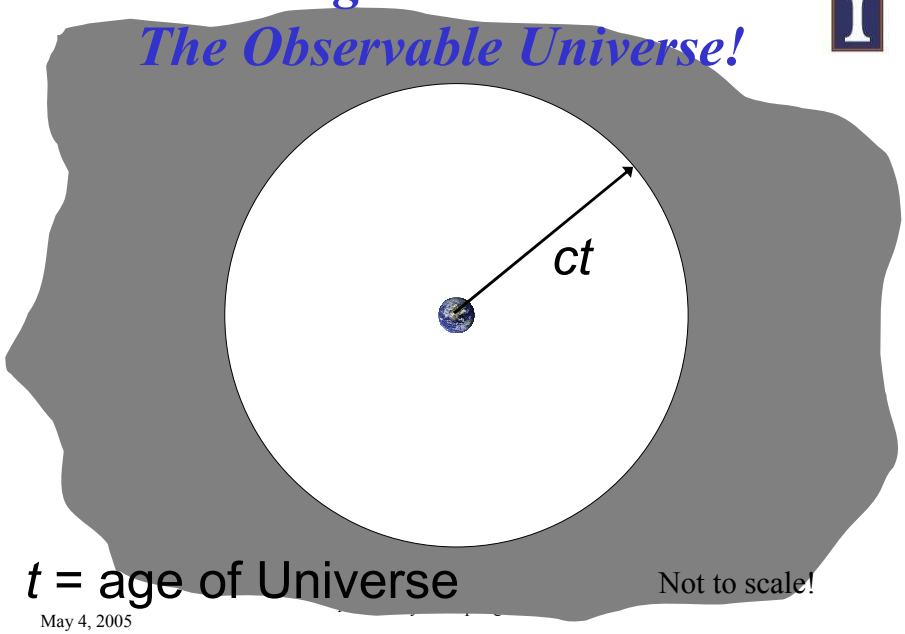
The Seeds of Galaxies

These small perturbations in temperature are the fluctuations that caused the large scale structures we see today. This is what formed the galaxies. All of this happened only 400,000 years after the Big Bang.



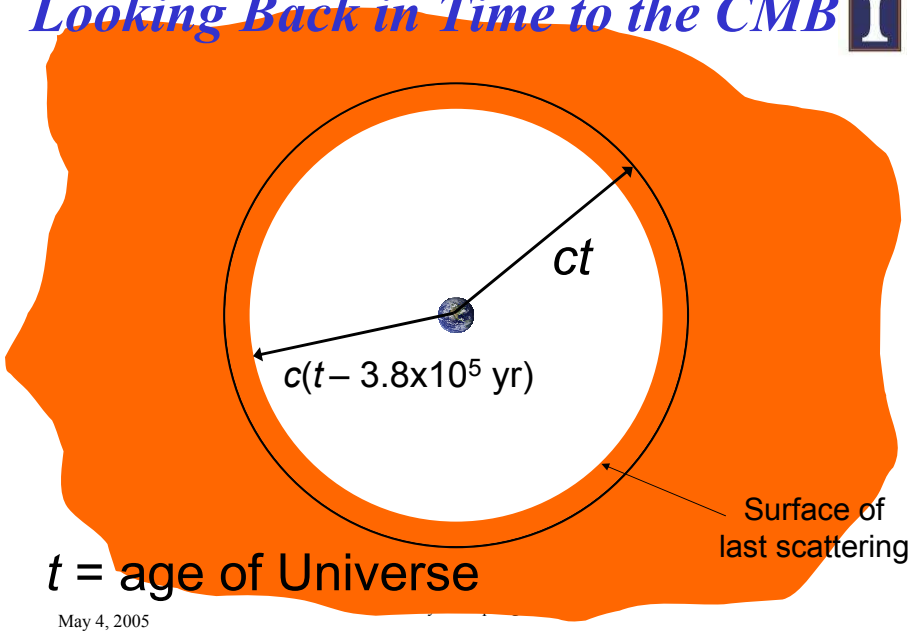
May 4, 2005

Looking Back in Time: The Observable Universe!



May 4, 2005

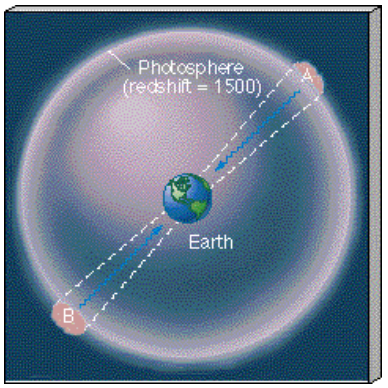
Looking Back in Time to the CMB



May 4, 2005

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 should they look the same?



THE VERY EARLY UNIVERSE

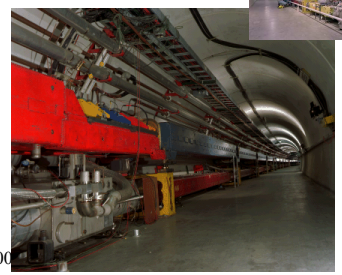
Since Big Bang works well so far, we have confidence to think about times earlier still:

$t << 1$ 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!

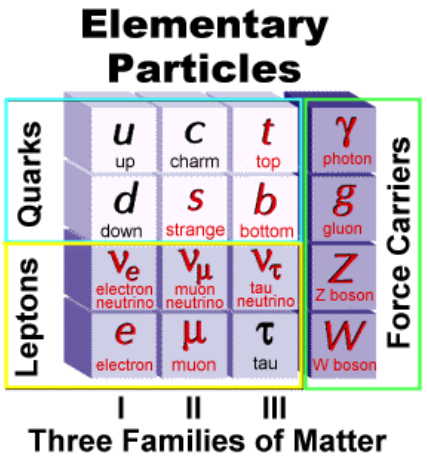
…but also…

"The Universe is the poor man's accelerator"

Probes conditions inaccessible at laboratories

A Brief History of Time

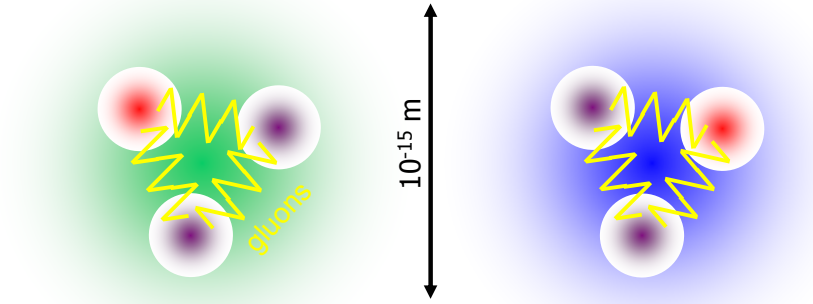
Basic Particles



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

Quarks

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

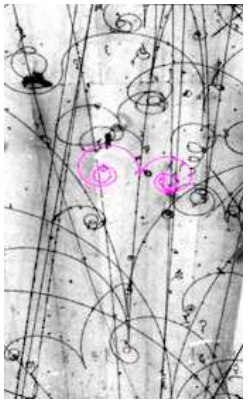


Proton (charge +1) =
2 "up" quarks (+4/3) +
1 "down" quark (-1/3)

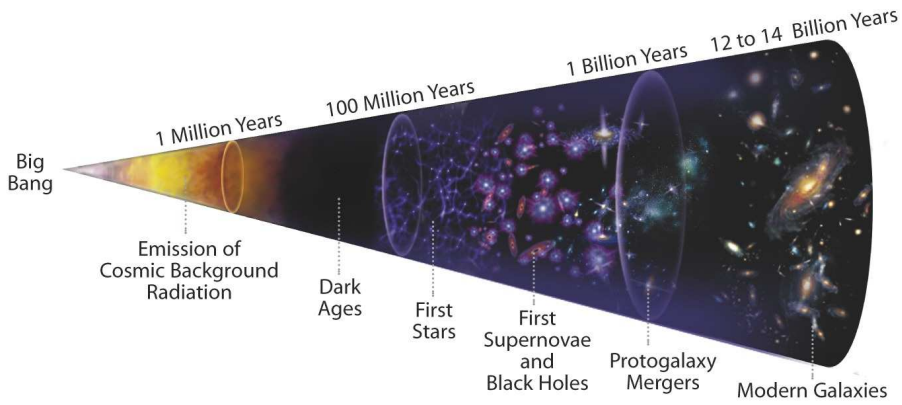
Neutron (charge 0) =
1 "up" quark (+2/3) +
2 "down" quarks (-2/3)

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!



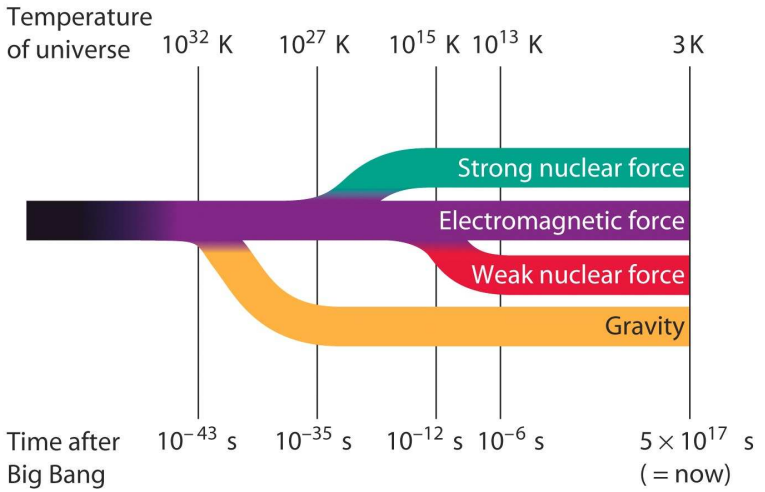
A Brief History of Time



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

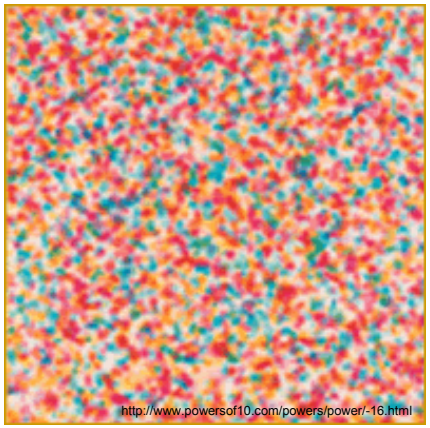
- Incredibly hot (more that 10^{32} K)
- Our current hypothesis – only one force in nature
  - The four forces were unified
  - Remains to be proven, as the theories we use to describe nature don't work in this era
- At the end of this era, gravity became a separate force
- Want a Nobel Prize? Develop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

Dis-Unification of the Forces



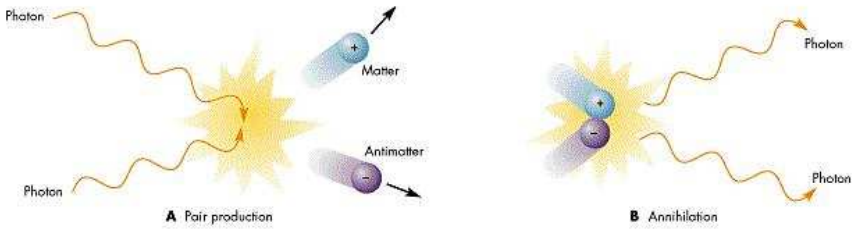
The GUT Era (until 10^{-35} sec)

- 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



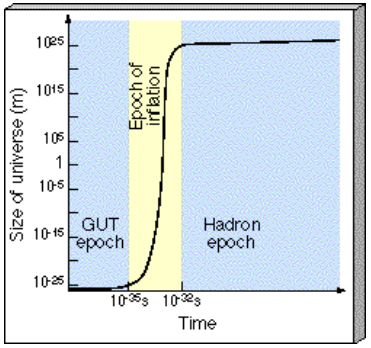
Matter and Anti-Matter

- 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



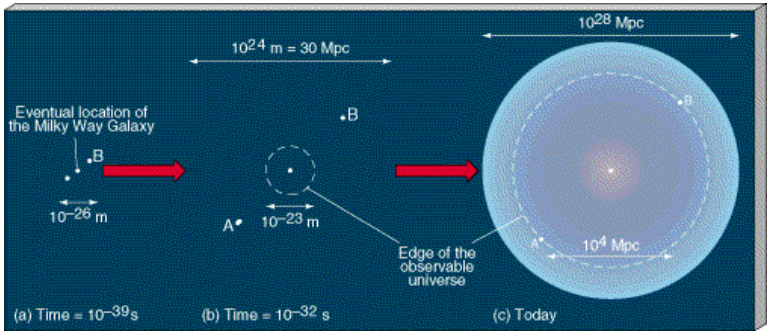
Inflation (10^{-35} to 10^{-32} sec)

- Idea: 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!



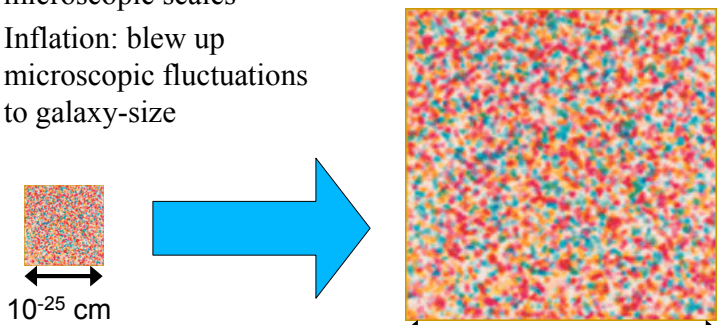
Inflation Solves the Isotropy Problem!

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



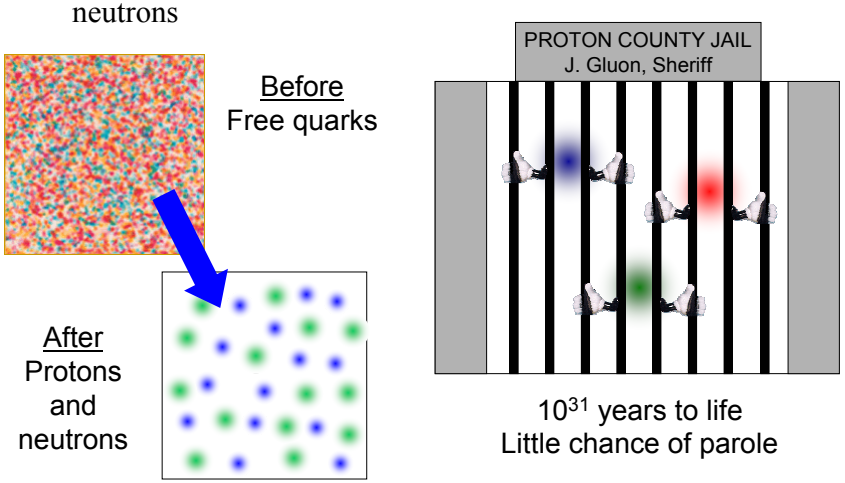
Origin of the CMB Fluctuations

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



Confinement of the Quarks

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

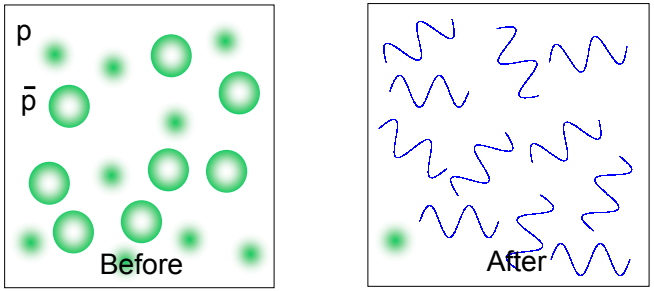


The Universe is Made of Matter

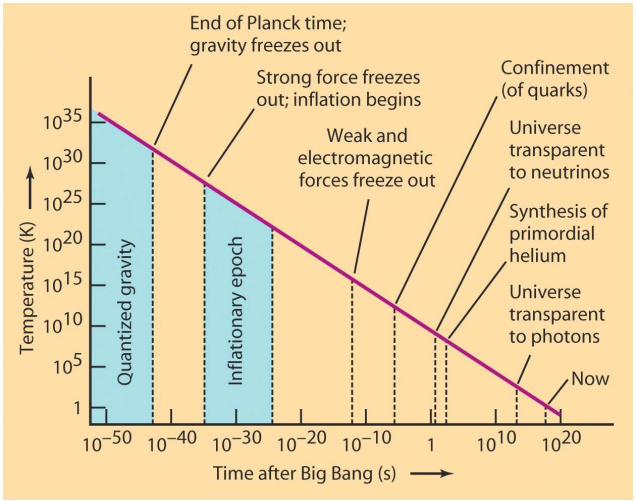
- You, and I, and the Earth are all made of matter not anti-matter
- The Moon is made of matter, not anti-matter
- Local "neighborhood" in Milky Way is matter, gas between the stars
- The Universe is made of matter
- How did this come to be?

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

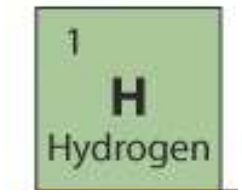


The End of the First Second

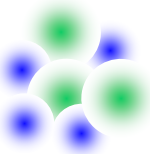


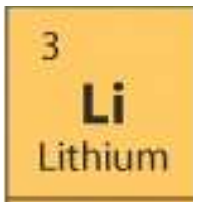
Big Bang Nucleosynthesis

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

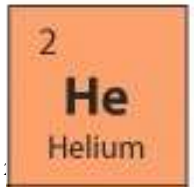


(a proton)

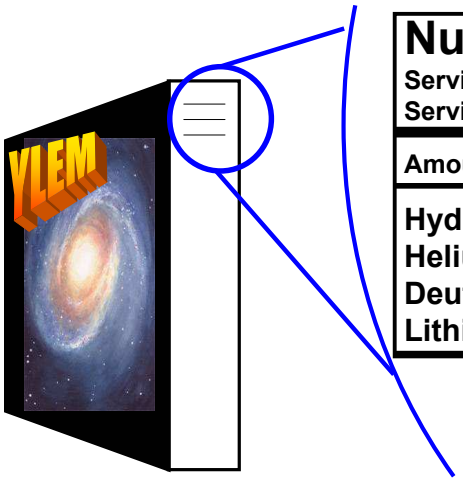




Also: Deuterium



End Result:
Big Bang Correctly Predicts Abundances



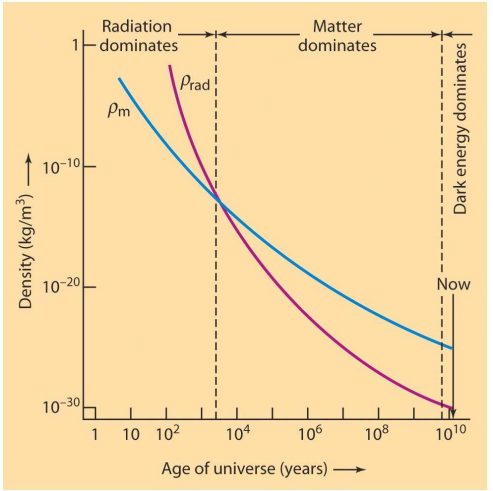
Nutrition Facts
Serving Size 1 g
Servings Per Universe many many

Amount Per Serving

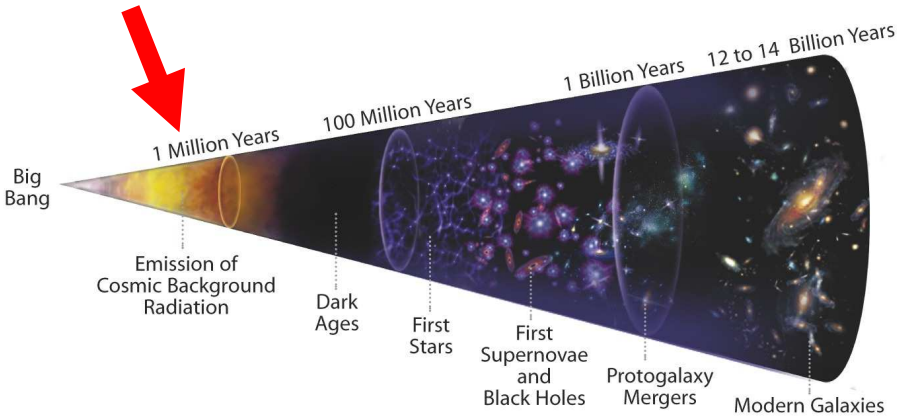
Hydrogen	**0.75 g**
Helium	**0.25 g**
Deuterium	**10^{-4} g**
Lithium, etc.	**10^{-10} g**

Radiation Domination

- In the early Universe, most of the energy was in radiation
- As the Universe expanded, photons were redshifted
  - Lost energy
- After 30,000 years, most of the energy of the Universe was in matter

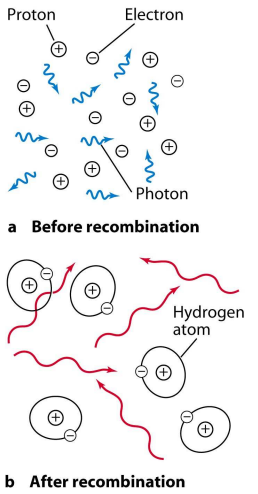


Origin of the CMB



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!

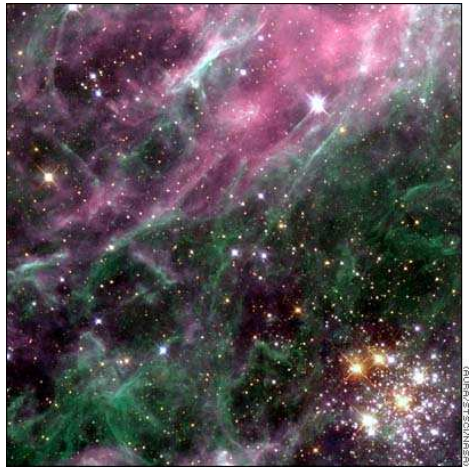


The Dark Ages

- 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

The First Stars

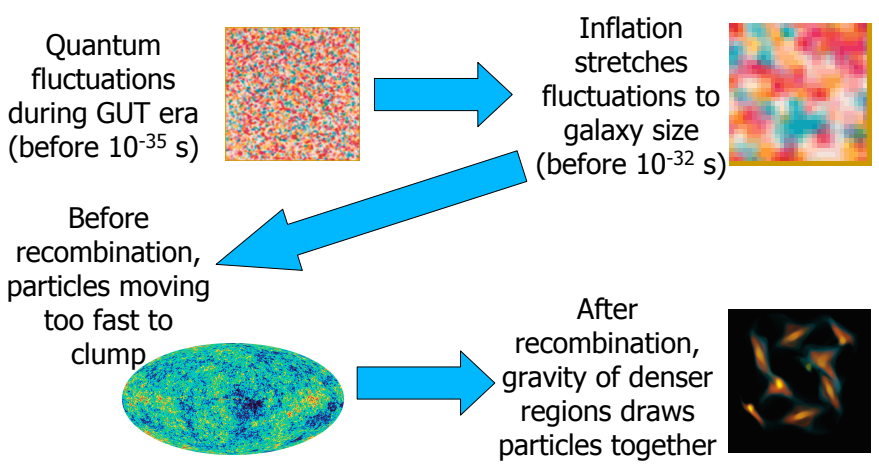
- We think the first stars began to form after about 100 million years
- Proto-galactic clouds are slowly collapsing – no galaxies yet
- Gave the Universe it first supply of heavy elements



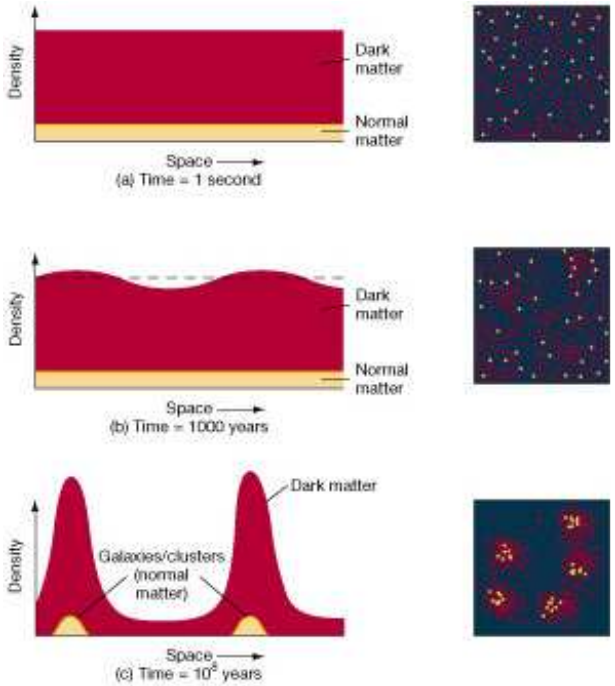
"Thinking Cap"

What if our solar system formed with the first generation of stars? How would our solar system be different? Would the Earth exist as a habitable planet?

The Beginnings of Galaxies



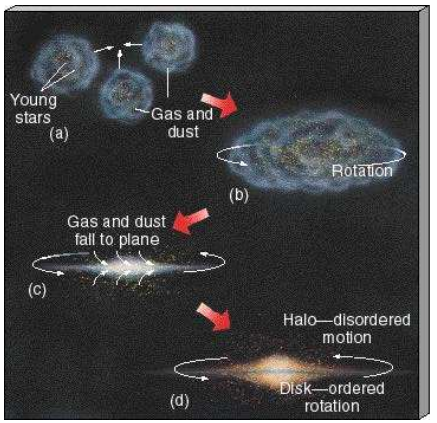
Quantum Fluctuations Were Good for Us

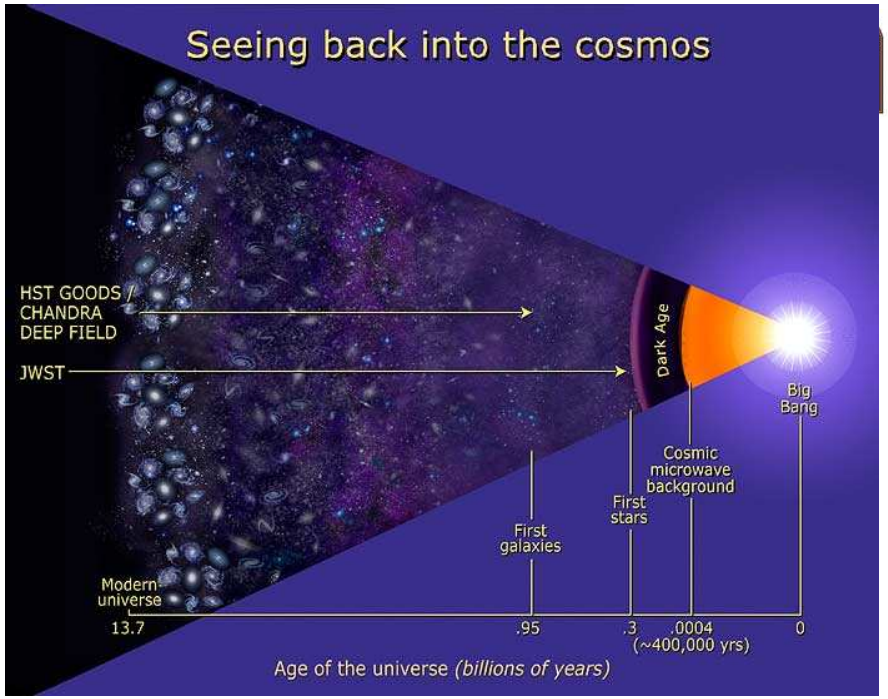


Gravity enhances the perturbations over time into galaxies.

Galaxy Formation

- Regions of higher density became the seeds of galaxies, clusters, and superclusters
- Collapsed under their own gravity
- Well-fed supermassive black holes at galaxy centers became quasars



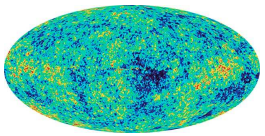


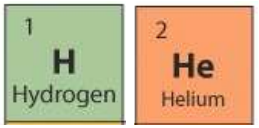
From the Home Office in Urbana, IL
Top 3 Reasons We Believe in the Big Bang

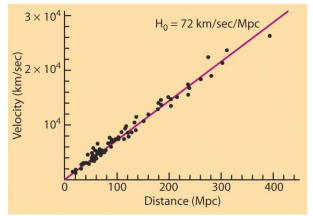
1. Cosmic Microwave Background
   - Big Bang working at about 500,000 yrs
   - Tiny fluctuations: "seeds" of galaxies
2. Big Bang Nucleosynthesis
   - H and (almost all) He come from the Big Bang
   - Big Bang working at 1 sec
3. The Hubble Law: $v=H_0 d$

   + 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

Both are observable!

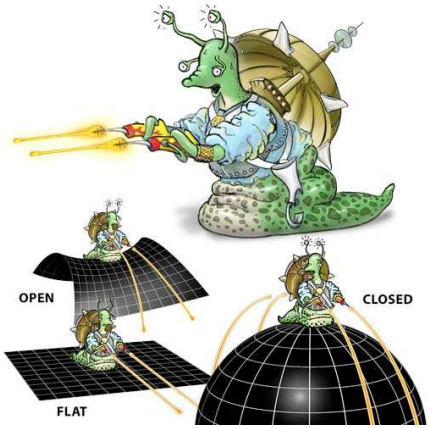
or

Our fate is a **quantitative** question :

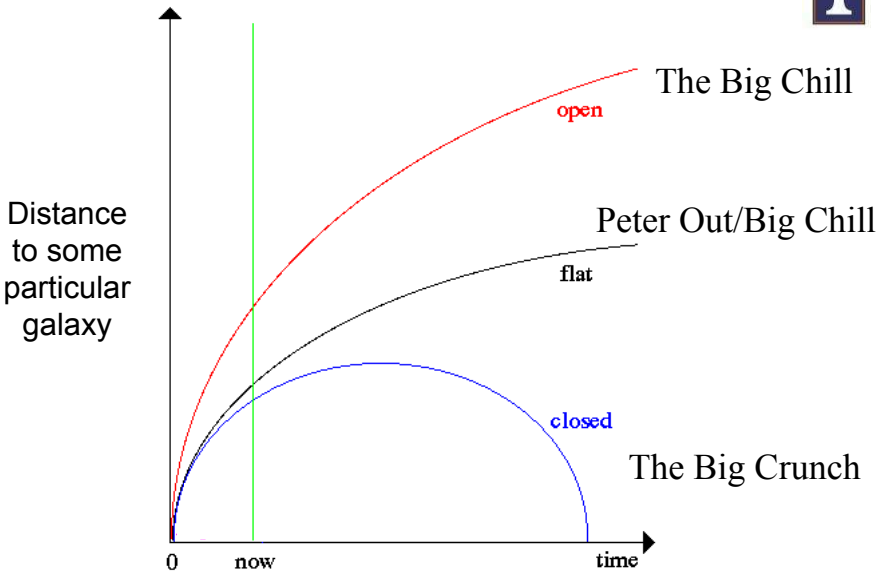
- **If our mass is small enough we expand forever.**
- **If our mass is large enough expansion halts, and we collapse.**

The Shape of Fate

- The fate of the Universe is governed by the shape of space
  - Determined by the density of mass and energy (gravity) vs. the rate of expansion
- Three possibilities:
  - **Flat** - gravity and expansion are balanced, expansion will stop as time goes to infinity
  - **Closed** - gravity of matter is strong enough that space curves in on itself
  - **Open** - expansion will continue forever



What kind of Universe do we live in?



Big Chill/Big Crunch

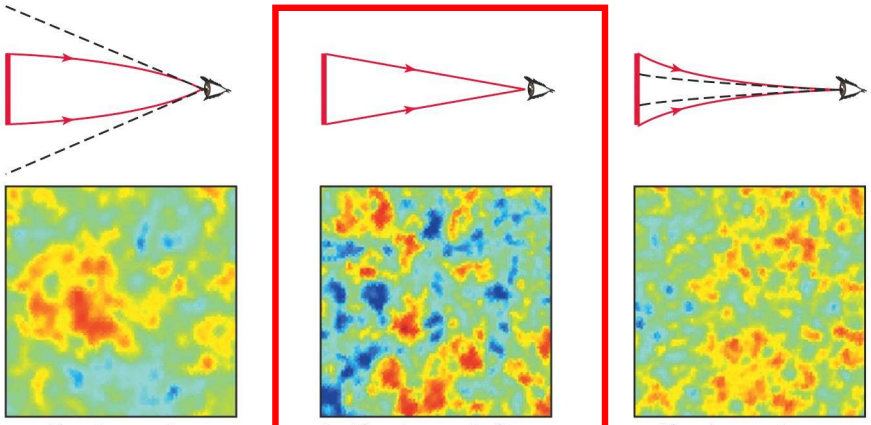
- An open or flat Universe will end in a **Big Chill**:
  - Galaxies exhaust their gas supply
  - No more new stars
  - Old stars eventually die, leaving only dust and stellar corpses
- A closed Universe will end in a **Big Crunch**:
  - Expansion will stop, and the Universe will recollapse
  - Ends 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

A Census of Matter

% of critical density

30% Dark matter

Needed to explain:
galaxy rotation curves
clusters of galaxies

0.5% Ordinary matter

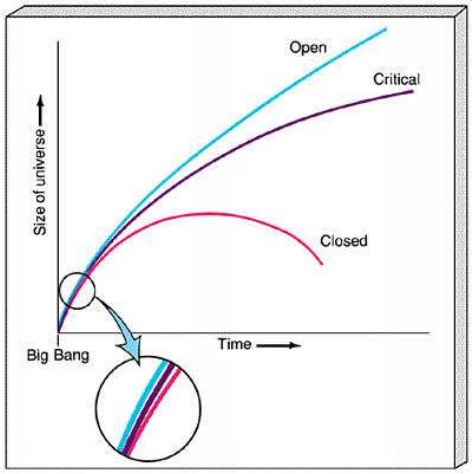
Made of protons, neutrons, and electrons

0.005% Cosmic Microwave Background

30.5% Total Not enough to make the Universe flat

So How Is The Universe Flat?

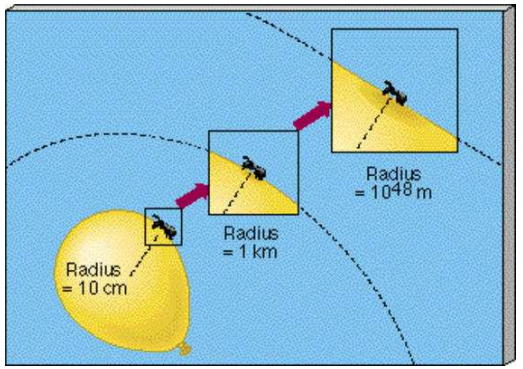
- Flat universe stays flat
- Open or closed universes rapidly deviate from flatness
- Our Universe is very nearly flat ⇒ fine tuning?



http://blueox.uoregon.edu/~jimbrau/astr123/Notes/Chapter27.html

Remember Inflation

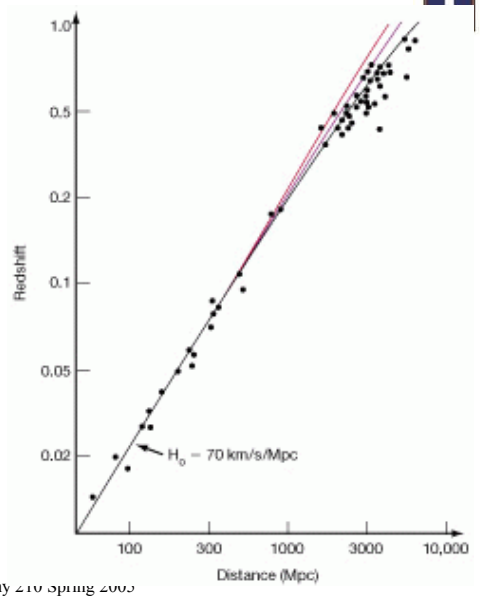
- The Universe went through a period of extremely rapid expansion
- Expansion by more than factor of 10^{50}!!
- This flattened the Universe
- Inflation makes the Universe very nearly flat!



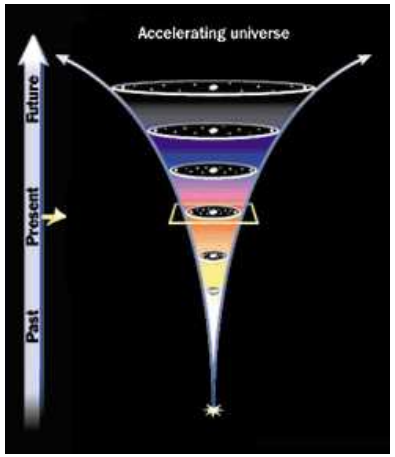
The Accelerating Universe!!!

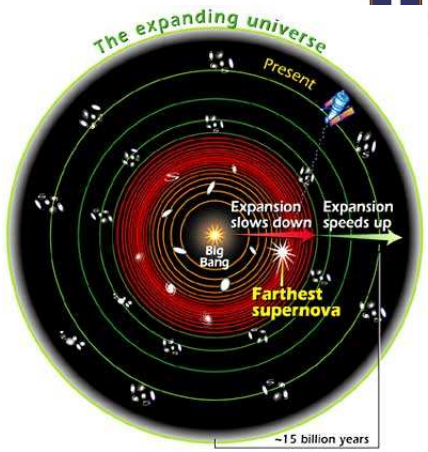
The universe is not slowing down at all. In fact, it's speeding up!!! We live in an accelerating universe!

It's as if there's another force pushing the universe apart – a Cosmological Constant!!!



The Accelerating Universe!!!



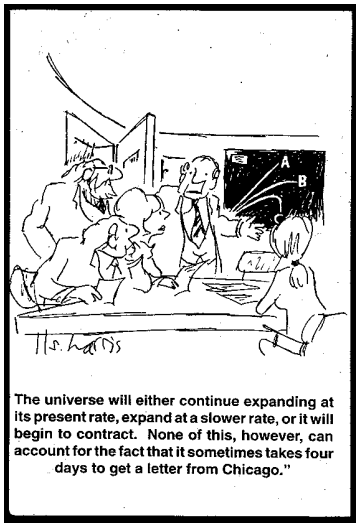


Whatever this force is, we *think* that it is growing stronger as the universe evolves. The more empty space in the universe, the greater the acceleration – as if the vacuum of space has energy.

What is Dark Energy?

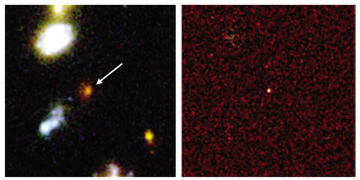
Dark Energy

- Inflation makes the Universe flat
- But 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!

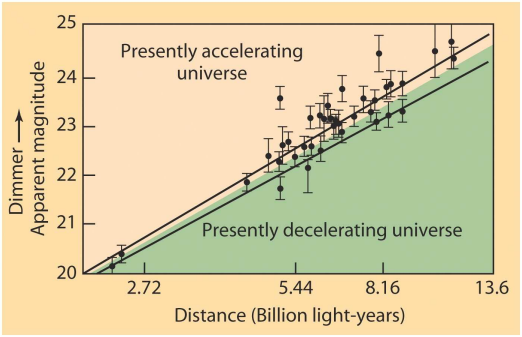


Evidence for Dark Energy

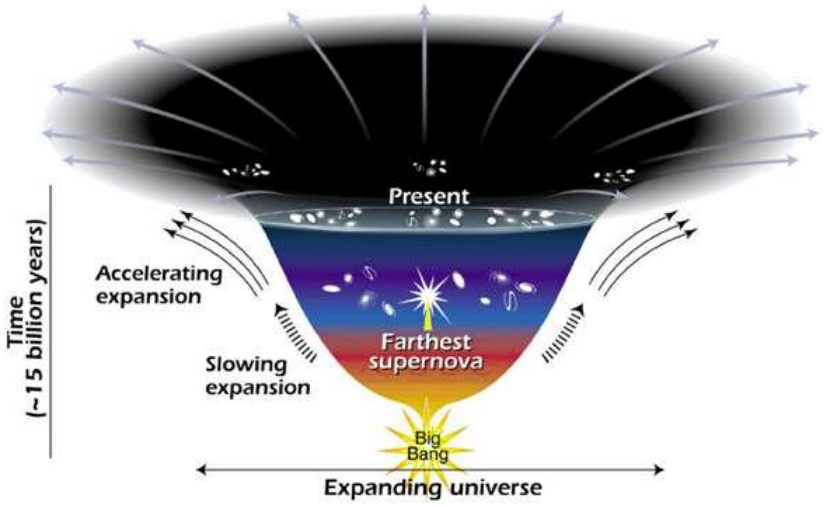
- Distant supernovae are dimmer than they should be if expansion is slowing down



Supernova 1997ff: the most distant supernova ever detected



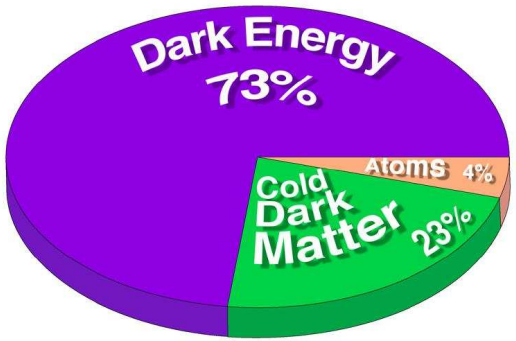
Effects of Dark Energy



http://www.lbl.gov/Publications/Currents/Archive/Apr-06-2001.html

The Accelerating Universe!!!

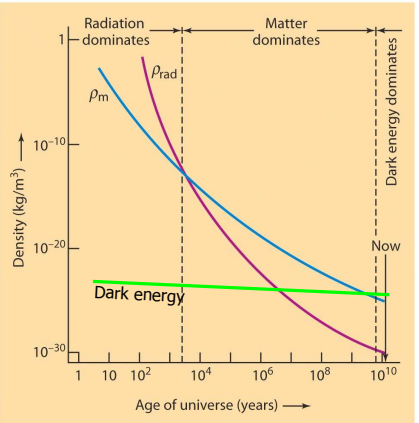
We appear to live in a universe with a flat shape, but which will go on accelerating forever. The universe is 13.7 billion years old, and is now dominated by dark energy. And it will only get worse – the more empty space, the more dark energy.



The Dark Energy even dwarfs dark matter! Regular matter is really insignificant. We *really* don't know anything about what's going on!!

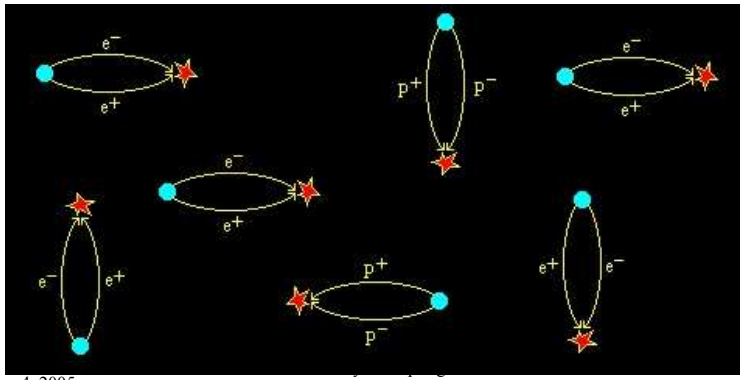
What Is the Dark Energy?

- Vacuum energy???
  - Even empty space has energy
  - Acts as repulsive gravity, competes with normal gravity
  - Constant in time and space
- Why is the strength of the repulsion what it is?
  - Allowed the Universe to slow down for billions of years before accelerating
  - And allowed galaxies to form



What is the Dark Energy?

We're clueless. There is one "traditional" theory– that particles and anti-particles are constantly being created and annihilated in the empty space (due to the uncertainty principle). For the instant these particles exist, they would act as a repulsive force. But our estimate of this force is off by a factor of 10^{122}.



The Distant Future

- Now – the Universe is (nearly) flat
- But the expansion is accelerating
  - An open Universe?
- The future depends on the nature of dark energy
- A new hypothesis suggests that dark energy is connected to the mass of neutrinos
  - As the Universe expands, neutrinos may get more massive
  - Add enough mass, and the Universe could become closed!

Think-Pair-Share

- What kind of a Universe would you want to live in? Open? Closed? Flat?

The Universe

- Began with a Big Bang
  - 13.7 billion years ago
- Still expanding and cooling
  - The rate of expansion is known and it is increasing
- 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 or nowhere!

History of the Universe

The Big Bang occurred 13.7 billion years ago. Since then

- +0.00001 seconds: protons, neutrons form
- +3 minutes: fusion of hydrogen to helium ends
- +100,000 years: release of the microwave background
- +400,000,000 years: Milky Way begins to form
- +2,000,000,000 years: era of galaxy formation/interaction
- +9,000,000,000 years: Birth of the Sun