Astronomy 122

This Class (Lecture 28):

The End

Next Class:

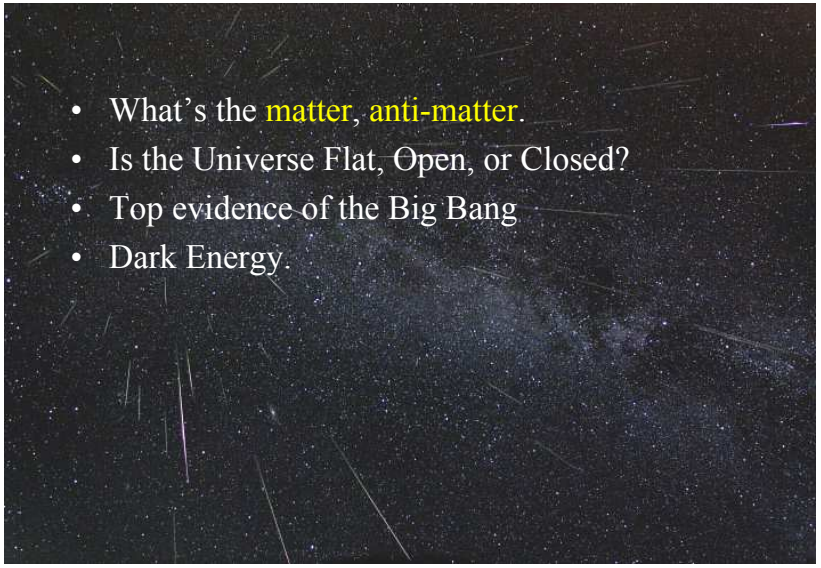
Last Discussion Section (review)

Music: *The Princes of the Universe* – Queen

Final

- In this room at 1:30pm-4:30pm on May 5th.
- Designed to be 2 hours long.
- Half is just like the midterm on the new material.
- 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.
  - 6 short answer questions
  - 11 true/false
  - ~55 multiple choice

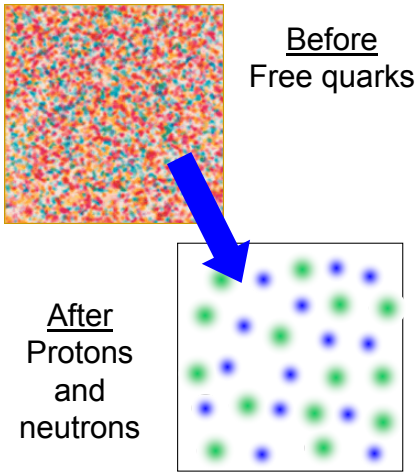
Outline

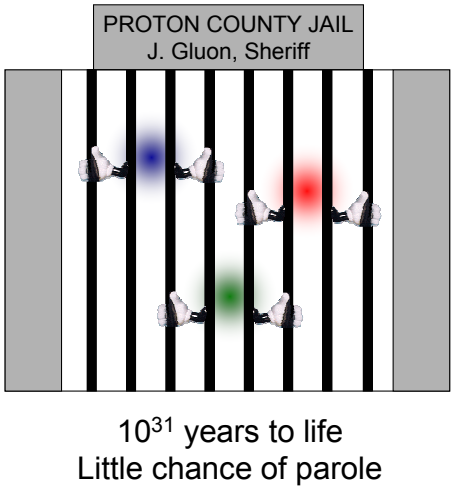


A Brief History of Time

Confinement of the Quarks

- 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?

The Early Universe and Antimatter

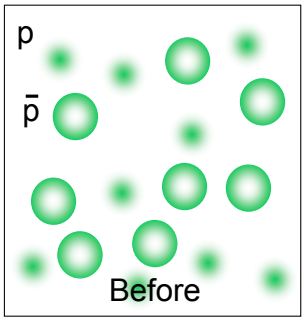
Strong evidence says:
The early universe had both matter and antimatter, but

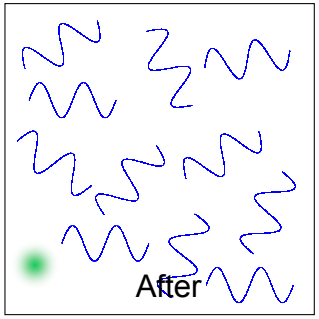
- For every 1,000,000,000 antimatter particles,
- There were 1,000,000,001 matter particles

Then annihilation happened, only the matter excess remained.

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





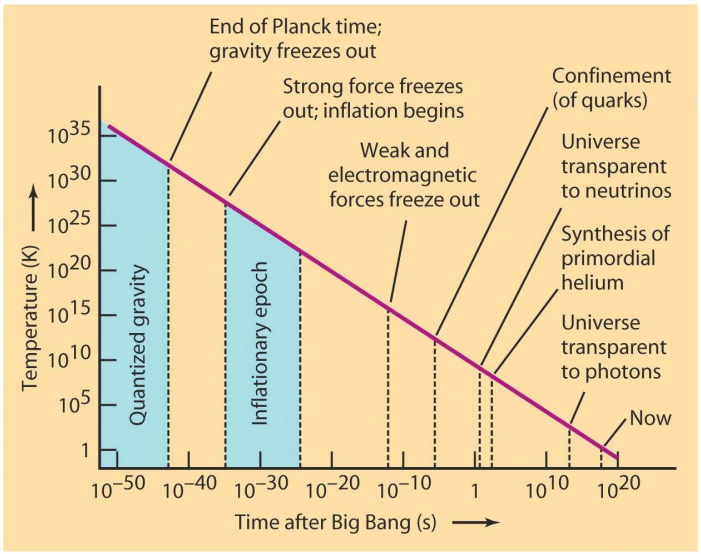
The Early Universe and Antimatter

How did the matter excess get there?
Most likely guess:

- The Universe began with equal amounts of matter & antimatter.
- But very high energy reactions slightly favored matter.
- Fermilab experiments: such reactions are possible!
- Stay tuned!

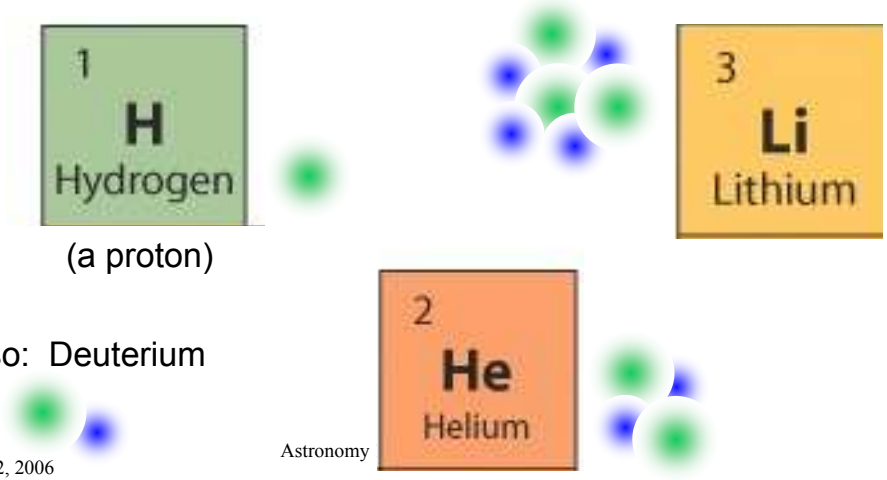
Example of inner space--outer space, particle--cosmology connection.

The End of the First Second

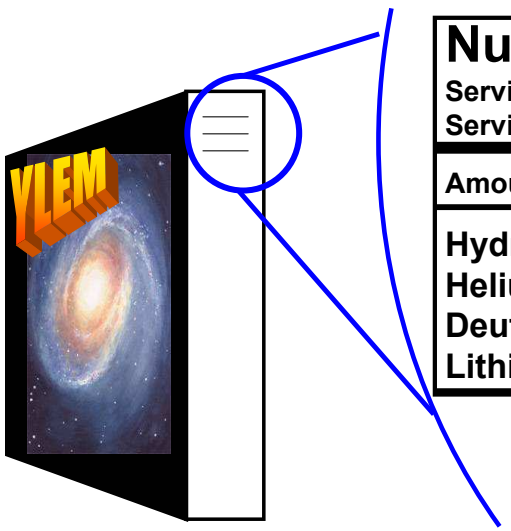


Big Bang Nucleosynthesis

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.



End Result: Big Bang Correctly Predicts Abundances



Nutrition Facts

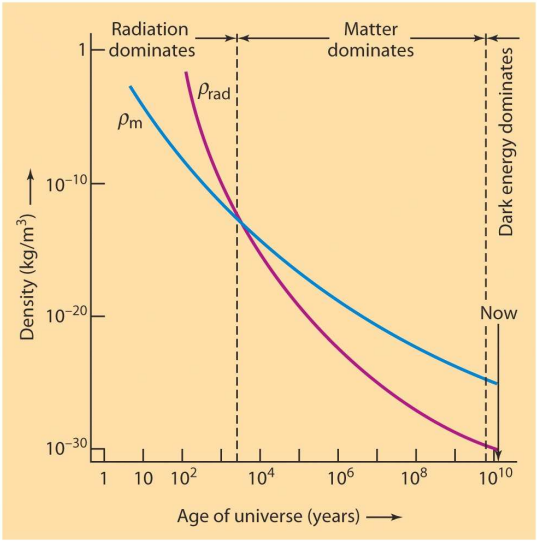
Serving Size 1 g
Servings Per Universe many many

Amount Per Serving

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

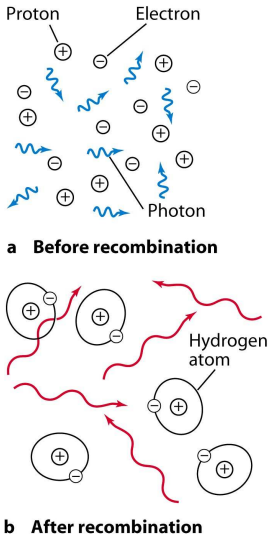
Radiation Domination

- 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

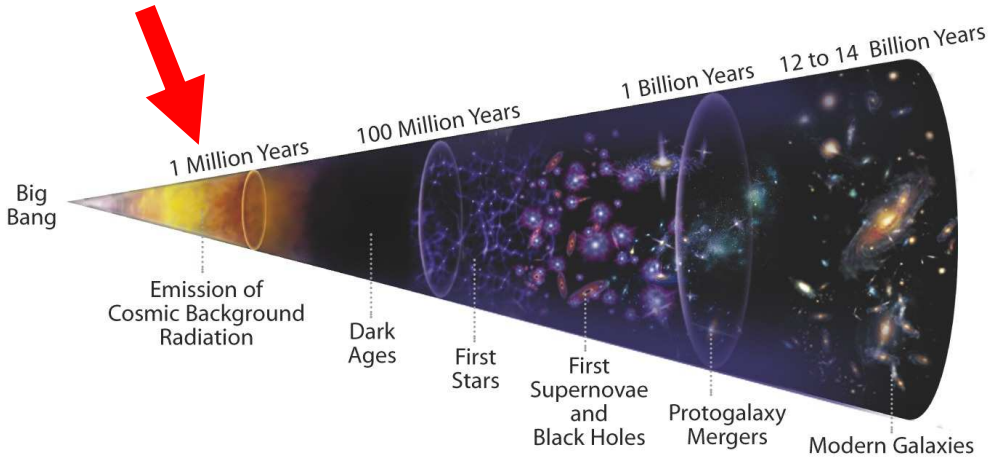


Era of Recombination

- 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

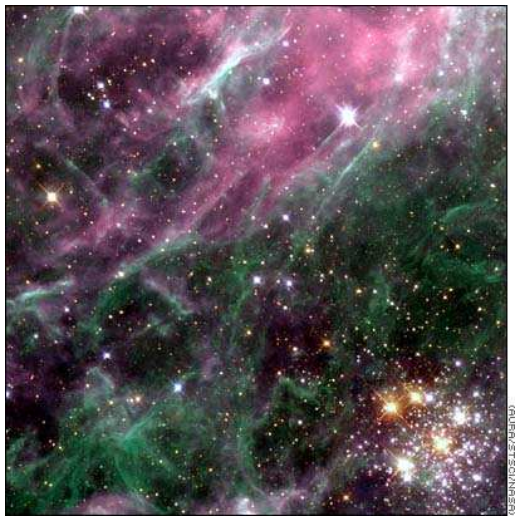


The Dark Ages

- 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 slowly 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

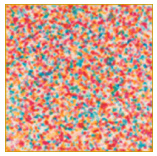


"Thinking Cap"

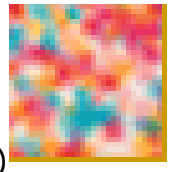
What if our solar system formed with the first generation of stars? How would our solar system be different? Would the Earth exist as a habitable planet?

The Beginnings of Galaxies

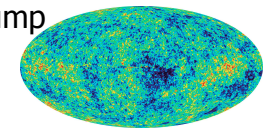
Quantum fluctuations during GUT era (before 10^{-35} s)



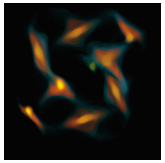
Inflation stretches fluctuations to galaxy size (before 10^{-32} s)



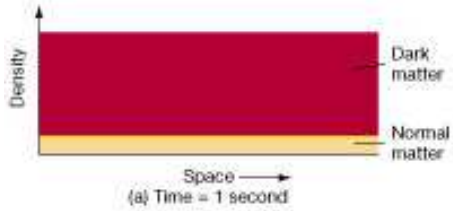
Before recombination, particles moving too fast to clump

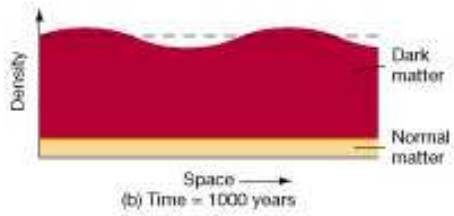


After recombination, gravity of denser regions draws particles together

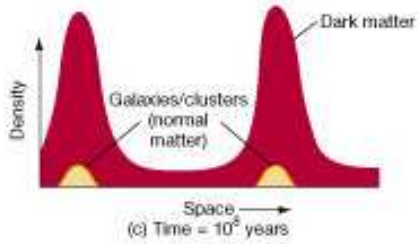


Quantum Fluctuations Were Good for Us



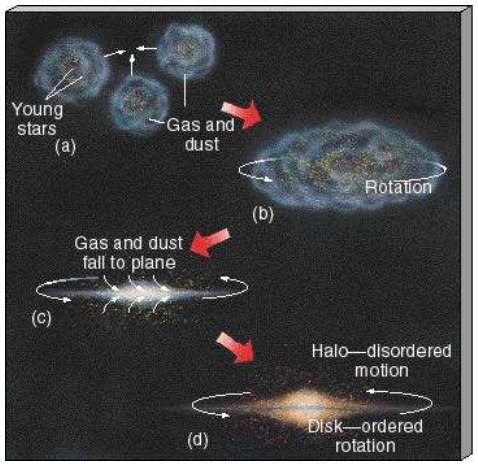


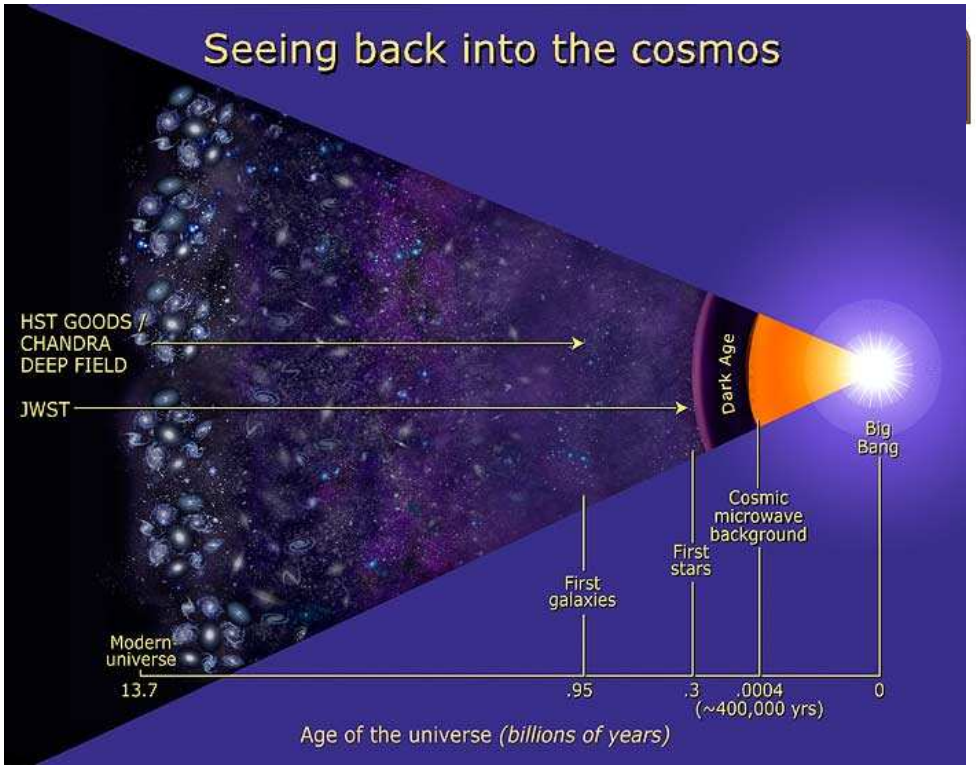
Gravity enhances the perturbations over time into galaxies.



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



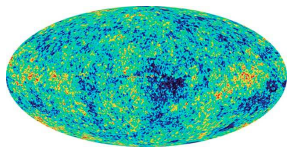


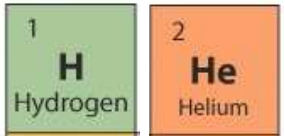
From the Home Office in Urbana, IL
Top 3 Reasons We Believe in the Big Bang

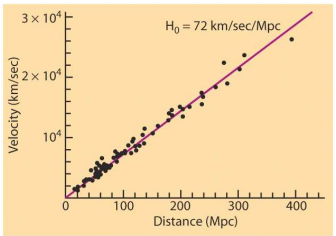
1. Cosmic Microwave Background
   - Big Bang working at about 500,000 yrs
   - Tiny fluctuations: "seeds" of galaxies
2. Big Bang Nucleosynthesis
   - H and (almost all) He come from the Big Bang
   - Big Bang working at 1 sec
3. The Hubble Law: $v=H_0 d$

   + 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

or

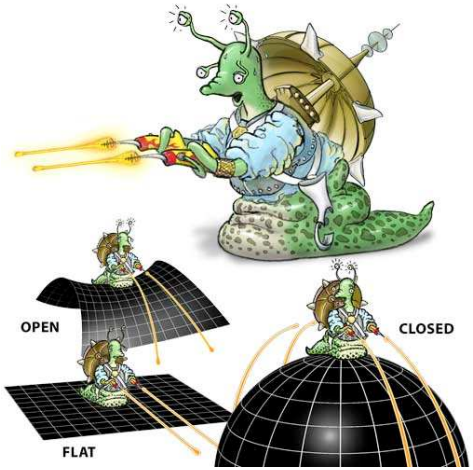
Both are observable!

Our fate is a **quantitative** question :

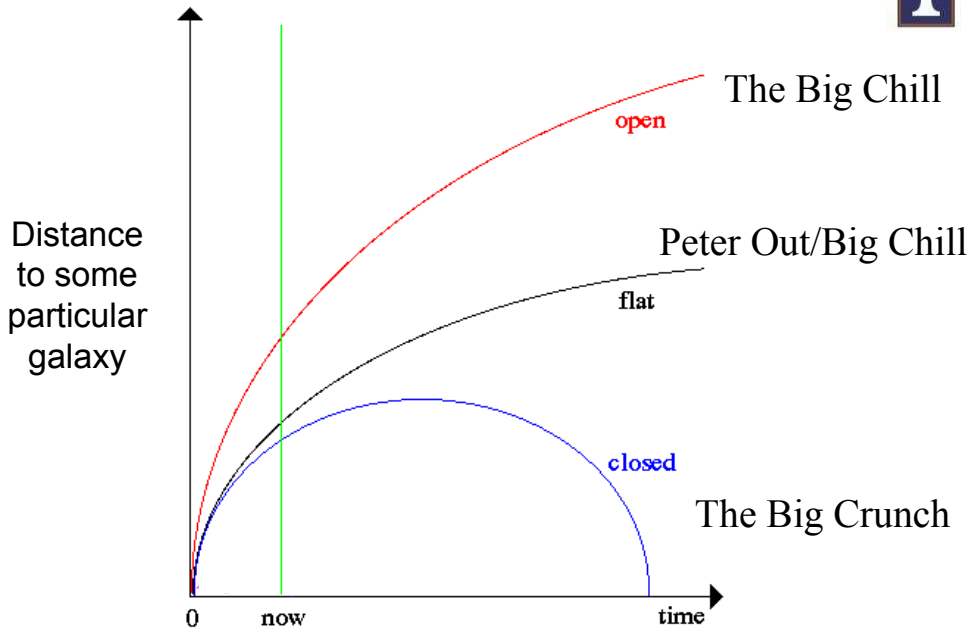
- **If our mass is small enough we expand forever.**
- **If our mass is large enough expansion halts, and we collapse.**

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 re-collapse
  - Ends as it began, incredibly hot and dense

Weigh Enough to Close the Universe?

% of critical mass

22% Dark matter

Needed to explain:
galaxy rotation curves
clusters of galaxies

4.5% Ordinary matter

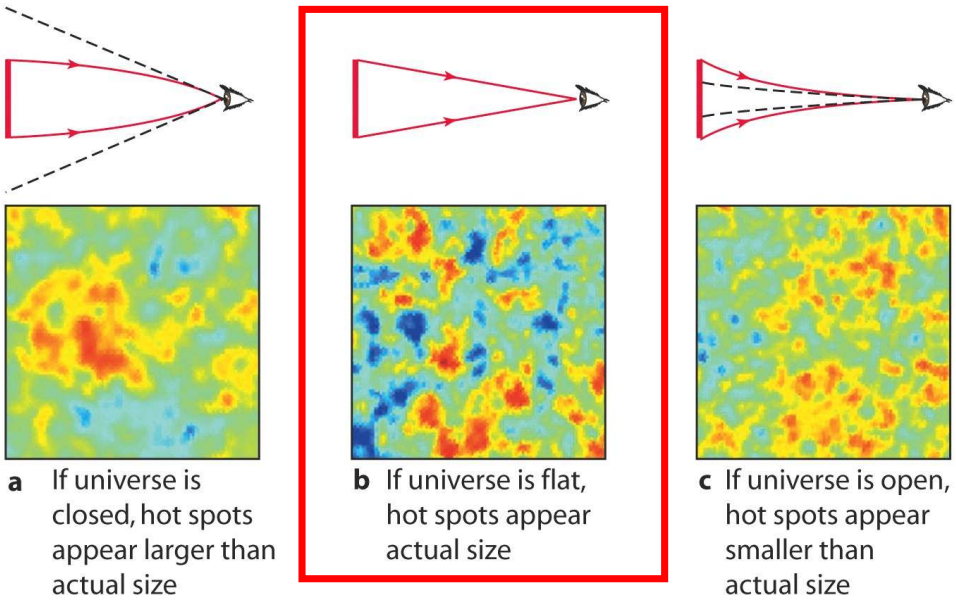
Made of protons, neutrons, and electrons

<1.5% Neutrinos

28% Total **Not enough to close the Universe**

CMB Measurements

Universe is Flat!!!!



Weigh Enough for a Flat Universe?

% of critical density

30% Dark matter
Needed to explain:
galaxy rotation curves
clusters of galaxies

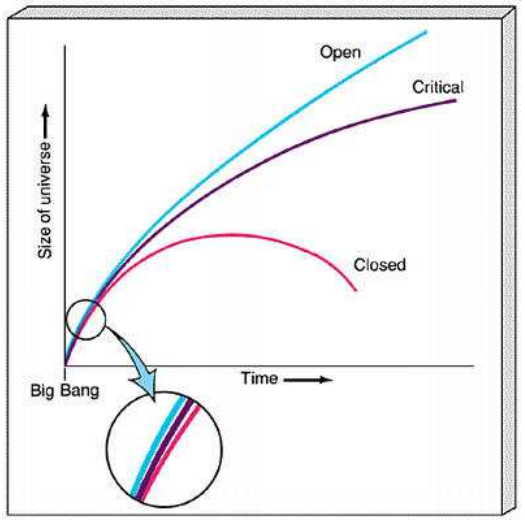
0.5% Ordinary matter
Made of protons, neutrons, and electrons

0.005% Cosmic Microwave Background

30.5% Total **Not enough for a flat Universe**

So How Is The Universe Flat?

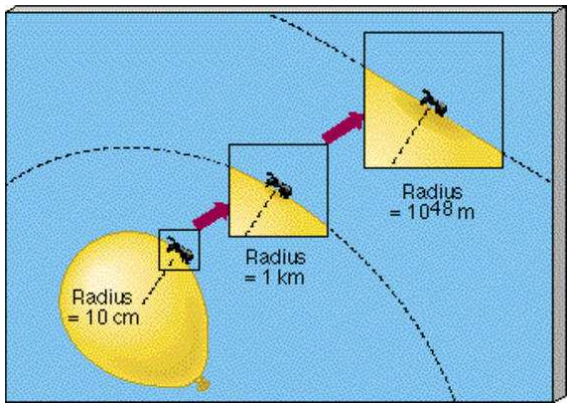
- Flat universe stays flat
- Open or closed universes rapidly deviate from flatness
- Our Universe is very nearly flat ⇒ fine tuning?



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

Remember Inflation

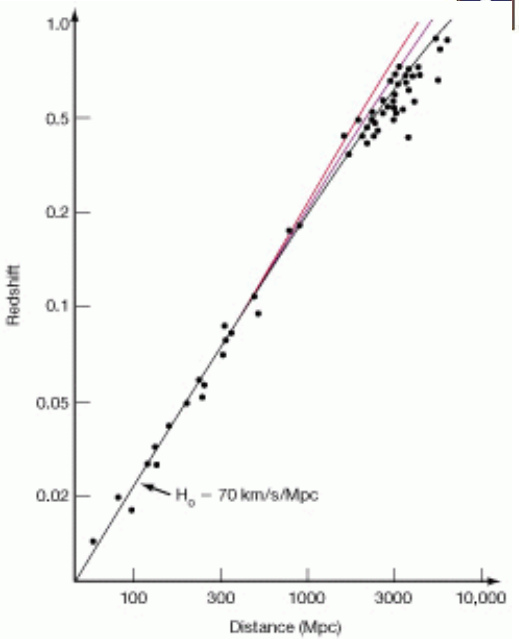
- The Universe went through a period of extremely rapid expansion
- Expansion by more than factor of 10^{50}!!
- This flattened the Universe
- Inflation makes the Universe very nearly flat!



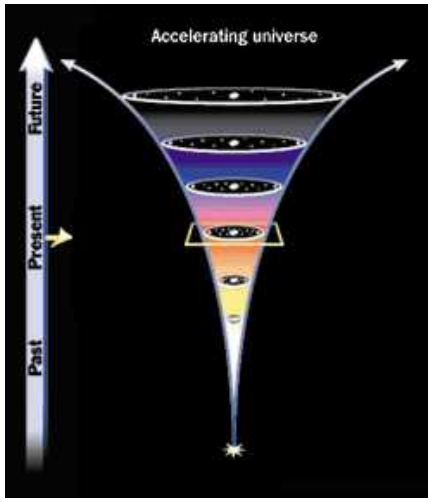
The Accelerating Universe!!!

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!!!

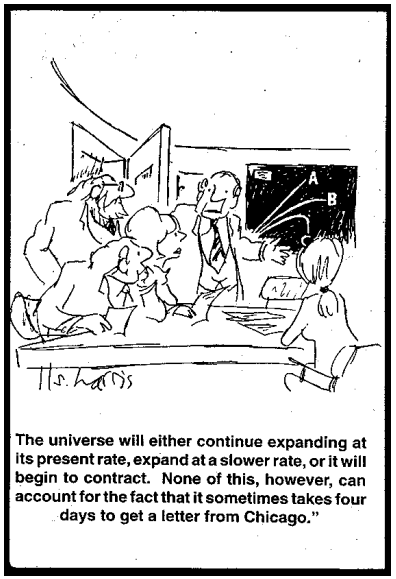


Whatever this force is, we *think* that it is growing stronger as the universe evolves. We call this extra force **Dark Energy**.

What is Dark Energy?

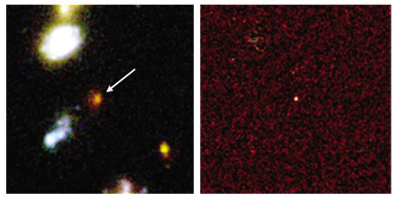
Dark Energy

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

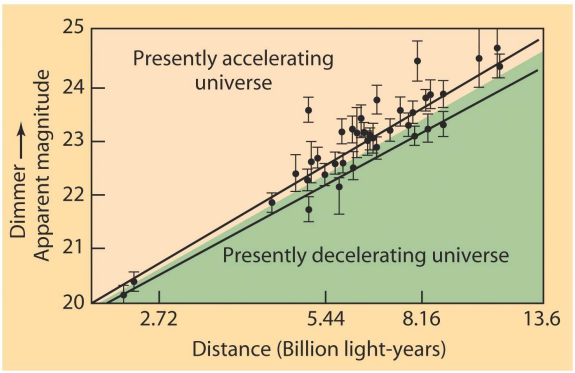


Evidence for Dark Energy

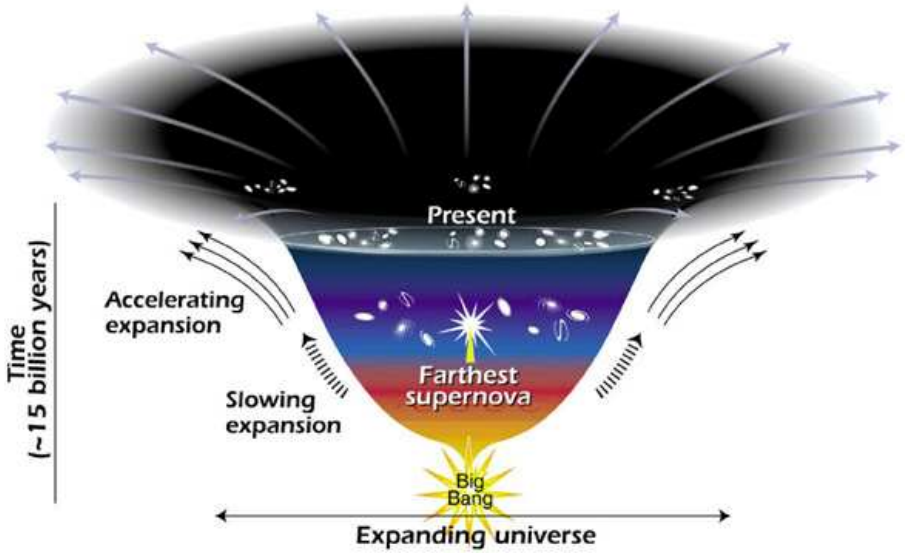
- Distant supernovae are dimmer than they should be if expansion is slowing down



Supernova 1997ff: the most distant supernova ever detected



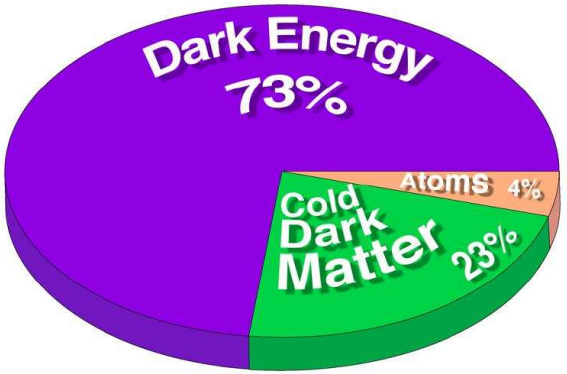
Effects of Dark Energy



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

The Accelerating Universe!!!

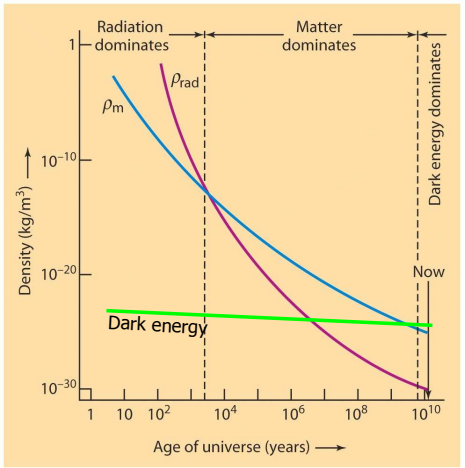
We appear to live in a universe with a flat shape, but which will go on accelerating forever. The universe is 13.7 billion years old, and is now dominated by dark energy. And it will only get worse – the more empty space, the more dark energy.



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

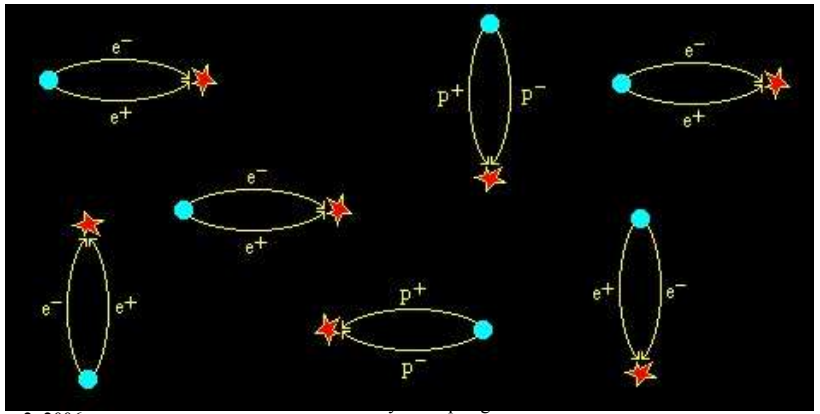
What Is the Dark Energy?

- 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



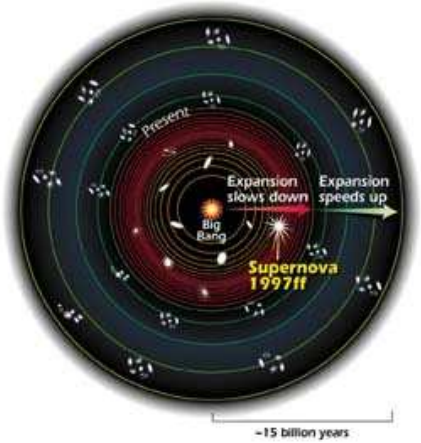
What is the Dark Energy?

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?

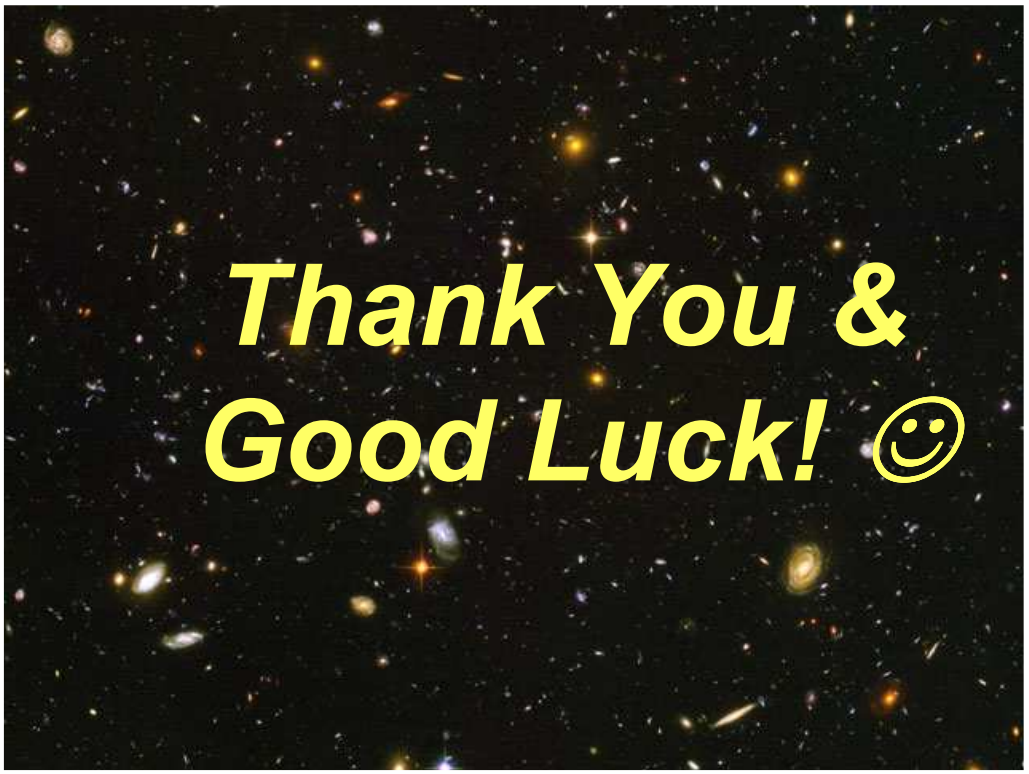
The Universe

- 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


Thank You &
Good Luck! ☺