Astronomy 150:
Killer Skies

This Class (Lecture 32):
This is the Way the Universe Ends

Next Class:
Monsters at the Center of Galaxies

HW 11 due on Dec 10th

Final: Dec 15th,
1:30pm-4:30pm in classroom

Music: The Universe Song– *Animaniacs*

Final

- In this classroom Dec15th, 1330-1630 (1:30pm-4:30pm).
- Will consist of
  - 18 question on Exam 1 material.
  - 18 question on Exam 2 material.
  - 35 questions from new material (Lect 23+).
  - +4 extra credit questions
- A total of 210 points graded out of 200 points, i.e. 5 points of extra credit.
- A normal-sized sheet of paper with notes on both sides is allowed.
- Exam 1and 2 are posted on class website (not Compass).
- I will post a review sheet

Online ICES

- ICES forms are available online.
- I **appreciate** you filling them out!
  - Not just the happiest/disappointed of the class.
- **Please** make sure to leave written comments. I find these comments the most useful, and typically that's where I make the most changes to the course.
- This is a new course, so comments are especially welcomed. Keep in mind constraints of a gen-ed though.

Question

Are you going to fill out an ICES form before the deadline?

a) Yes
b) No
c) I don't like ice in my beverages.

Outline

- Evolution of the Universe
- The fate of the Universe
  - Big Crunch
  - Big Chill
  - Big Rip

The Universe

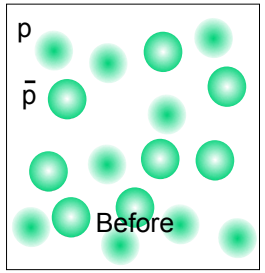
- Began with a Big Bang
  - 13.7 billion years ago
- Still expanding and cooling
  - The rate of expansion is known
- It is BIG
  - As far as we are concerned, it is infinite in any direction
- The universe is homogeneous and isotropic
  - **Homogeneous** - The same "stuff" everywhere
  - **Isotropic** - The same in all directions
- Our place in the Universe is not special
  - Extension of the Copernican revolution
- The center of the Universe is everywhere!

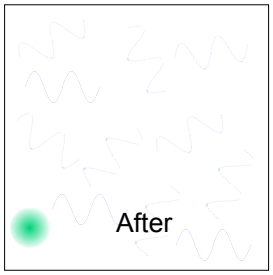
The Universe: Timeline

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

Annihilation of the Anti-matter

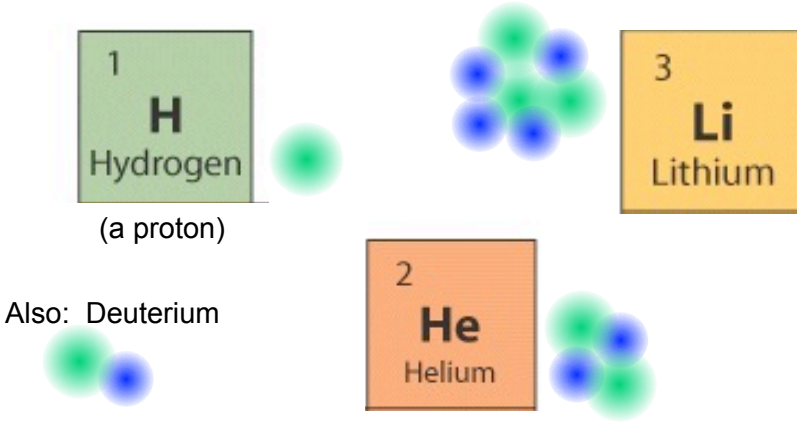
- 10^{-4} seconds:
  - Temperature dropped below the level at which photons have enough energy to create proton-anti-proton pairs
  - Remaining pairs annihilated → radiation
  - 1 proton in 10^9 had no partner! That's us.
  - **The first hydrogen atoms (ionized– no electrons— but there)**



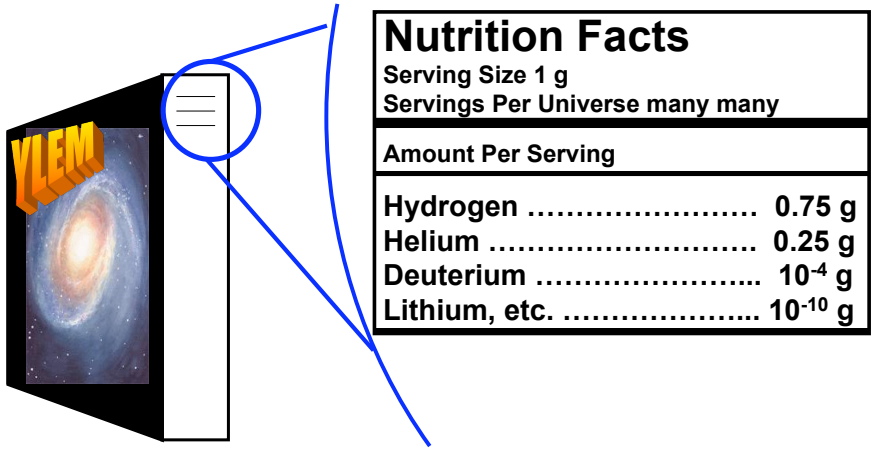


Big Bang Nucleosynthesis

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

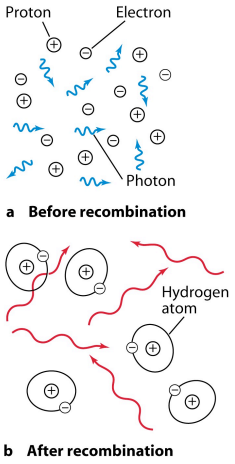


End Result: Big Bang Correctly Predicts Abundances

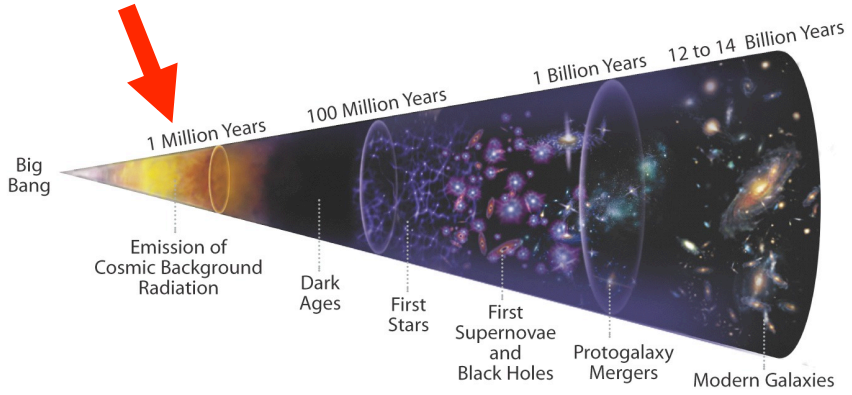


Era of Recombination

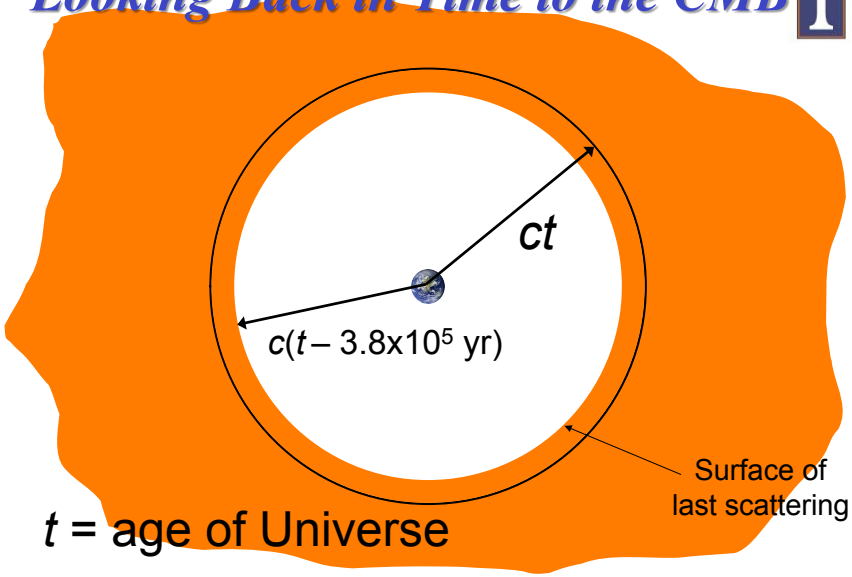
- In early Universe, photons were energetic, kept atoms ionized
  - protons and electrons couldn't make neutral hydrogen atoms
- After 380,000 years, photons couldn't ionize hydrogen anymore
  - Expansion of space stretched photons' wavelengths
  - Not enough energy to ionize hydrogen
  - Universe became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



Origin of the CMB

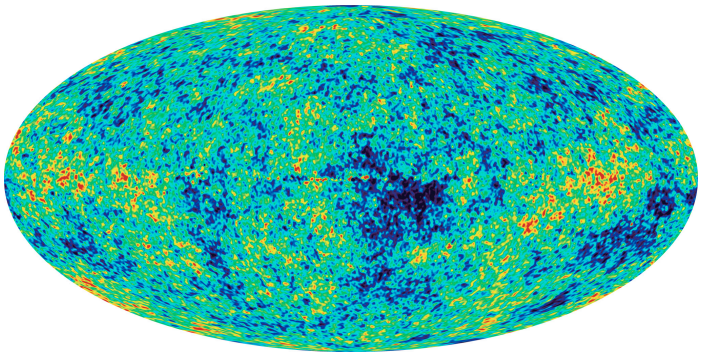


Looking Back in Time to the CMB



The Seeds of Galaxies

These small perturbations in temperature are the fluctuations (smaller than 1 in a 100,000) that caused the large scale structures we see today. This is what formed galaxies. All of this happened only 380,000 years after the Big Bang.



- After recombination came a period known as the Dark Ages
  - 380,000 to 200 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/

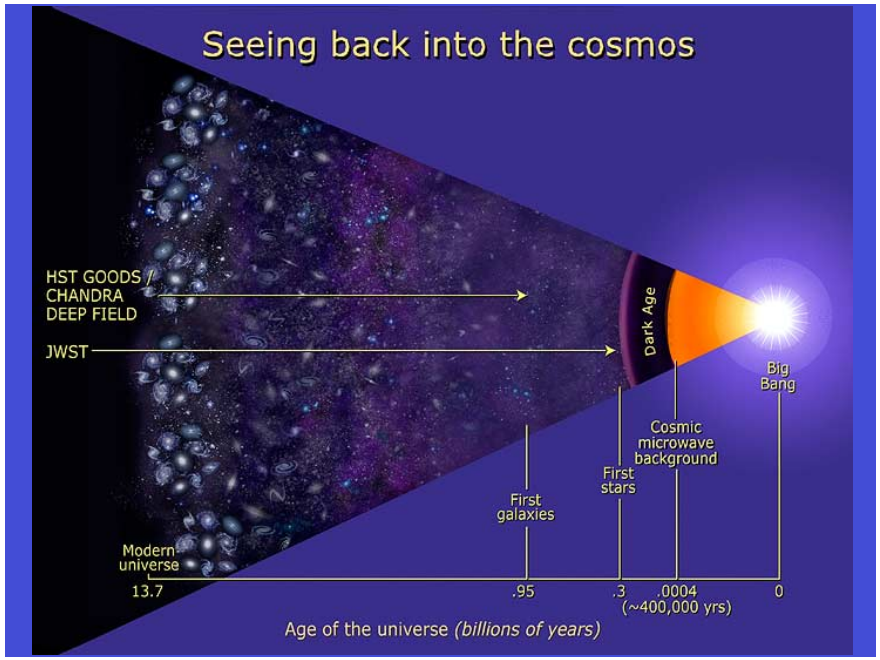
The First Stars

- We think the first stars began to form after about 200 million years
- Proto-galactic clouds are slowly collapsing – no galaxies yet
- Remember mostly hydrogen gas with very few metals.

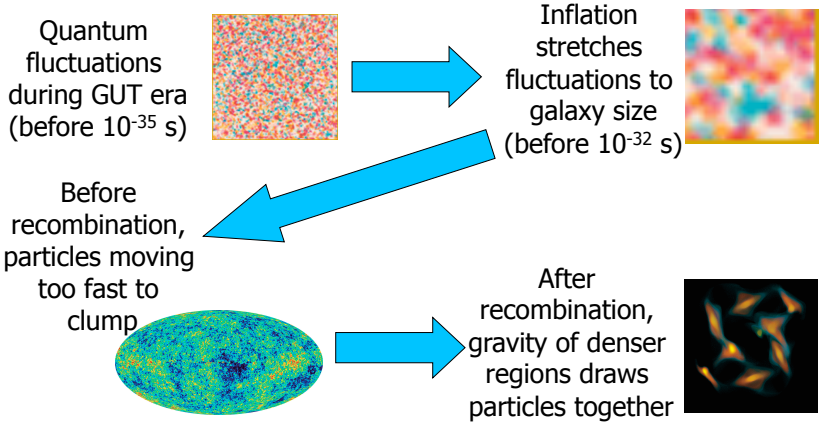
Question

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 Beginnings of Galaxies



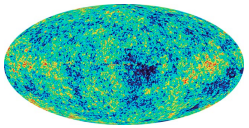
From the Home Office in Urbana, IL

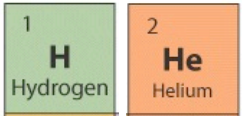
Top 3 Reasons We Believe in the Big Bang

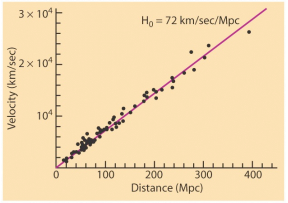
1. Cosmic Microwave Background
   - Big Bang working at about 380,000 yrs
   - Tiny fluctuations: "seeds" of galaxies
2. Big Bang Nucleosynthesis
   - H and (almost all) He come from the Big Bang
   - Big Bang working at 1 sec
3. The Hubble Law: $v=H_0 d$

   + Einstein's General Relativity

   = Expanding Universe with an age of 13.7 billion yrs







One of the most successful scientific theories of all time!

Question

Which of the following is not evidence of the Big Bang?

a) Hubble's law.
b) Big Bang Nucleosynthesis.
c) Olber's paradox.
d) Cosmic Microwave Background

The Universe: Timeline

- Big Bang: 13.7 billion years ago
- GUT era: $+10^{-35}$ second, energy and quarks
- Inflation: 10^{-35} to 10^{-32} seconds, Universe expands by more than 10^{50}!
- Quark confinement: 10^{-32} to 10^{-6} seconds, protons and neutrons form
- 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 200 million years, gravity works on stuff
- Stars: 200 million years, first stars form, protogalaxies

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

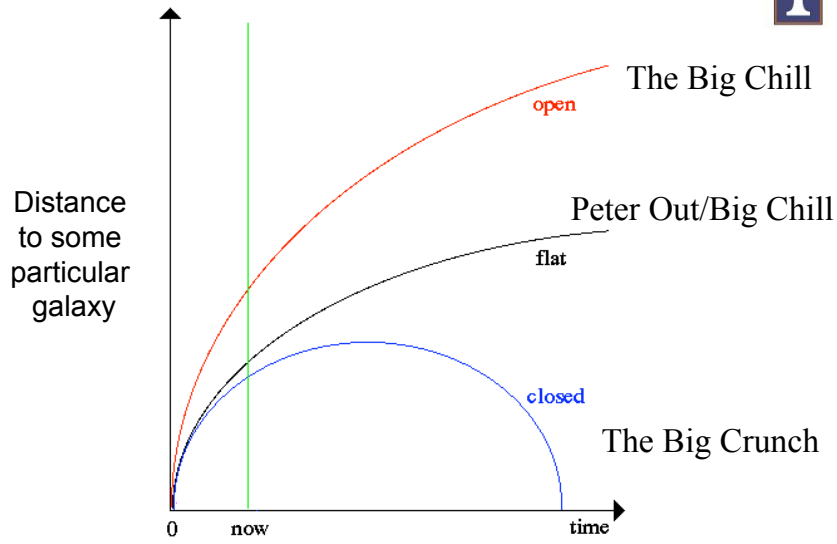
Both are observable!

or

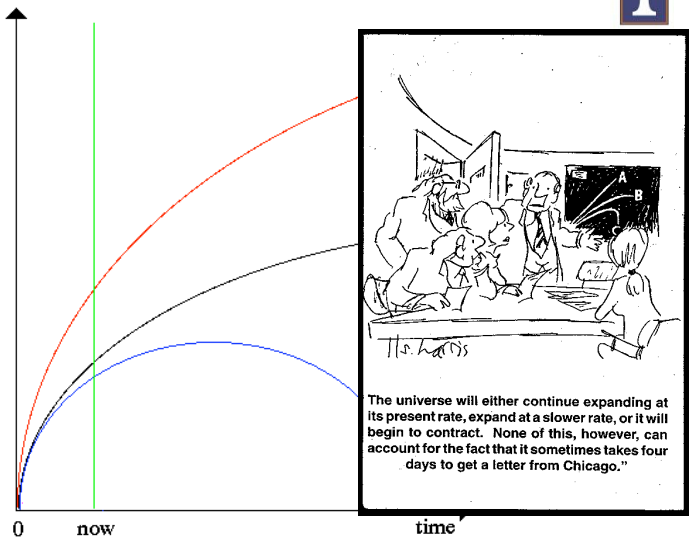
Our fate is a **quantitative** question :

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

What kind of Universe do we live in?



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

Question

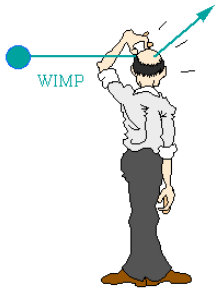
Our Universe could be one of three types: Open, Closed, or Flat. What would happen to a closed Universe?

a) No one else could get in.
b) It would expand forever.
c) It would just barely expand forever.
d) It would expand for a while, then eventually begin to re-collapse on itself.
e) It would expand, then slow down, then expand faster.

Dark Matter

- Outweighing regular matter is Dark Matter, probably some heavy exotic particle created during the Big Bang. (Weakly Interacting Massive Particle– WIMPs?).
- As mentioned before, 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"

How to search for WIMPs?



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

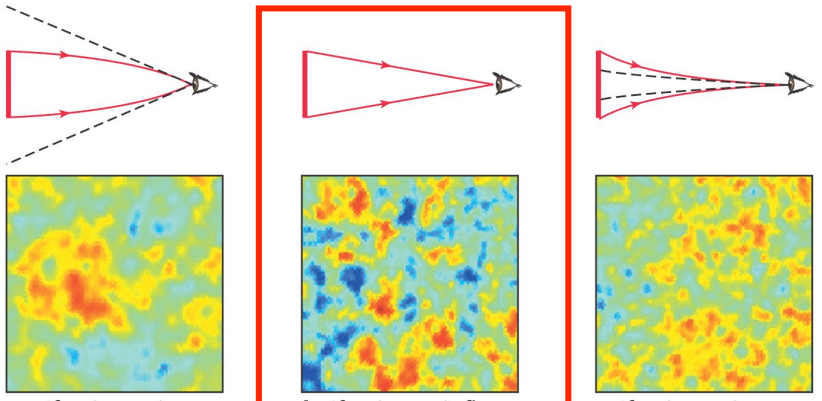
How Much Do We Weigh?

% 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

So we live in an open 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

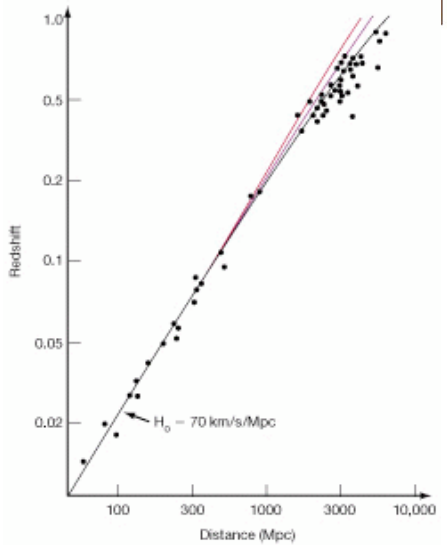
- The Universe will just barely expand forever, getting cooler and cooler.
- If all of the mass, dark+regular, isn't enough, **then what's up**?
- The fate of the Universe is really dependent on the amount of matter and energy in the Universe → $E = mc^2$

We must be missing some extra mass/ energy?

The Accelerating Universe!!!

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

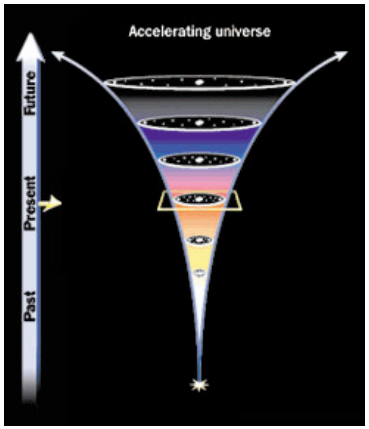
It's as if there's another force pushing the universe apart – a Cosmological Constant!!!

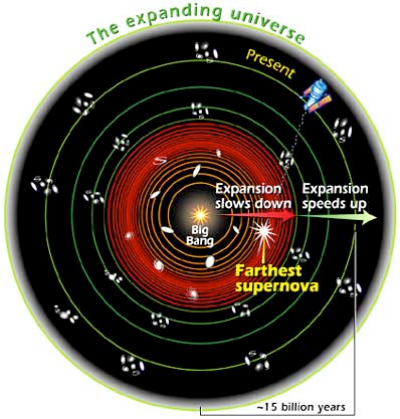


Dark Energy

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

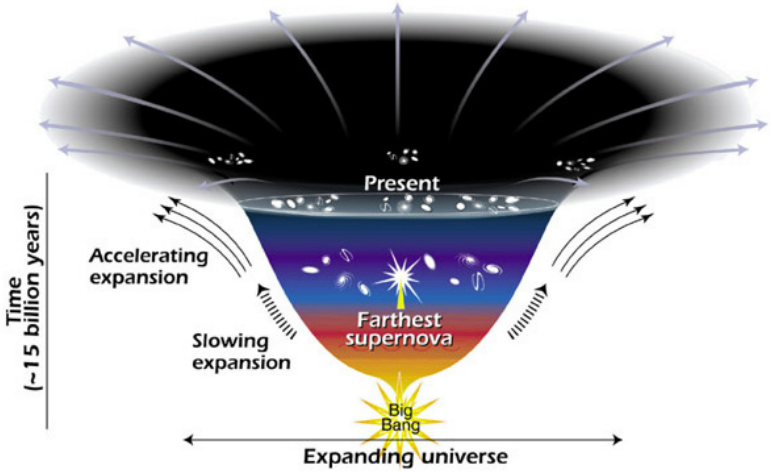
The Accelerating Universe!!!





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.

Effects of Dark Energy



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

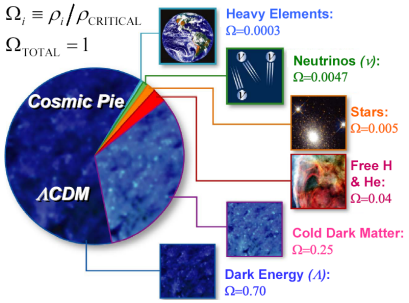
Question

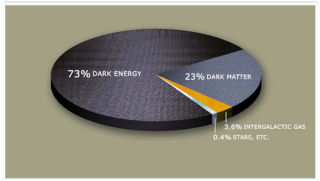
Based on measurement of the CMB, we live in a flat Universe. But there is not enough known mass to account for this. What's up?

a) We must be underestimating the amount of Dark Matter.
b) It would expand forever.
c) It would just barely expand forever.
d) We have something called Dark Energy.
e) It would expand, then slow down, then expand faster.

The Accelerating Universe!!!

The universe is 13.7 billion years old, and it is now dominated by dark energy.

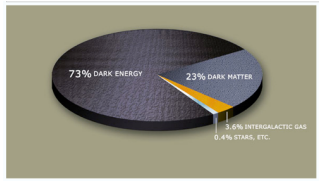




Dark Energy even dwarfs dark matter! Regular matter is really insignificant. We *really* don't know anything about what's going on!!

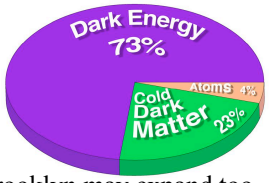
The Accelerating Universe!!!

- But, we are still in very speculative times here.
- How the Universe ends will depend on the nature of Dark Energy.
- If it really acts like a cosmological constant (go Einstein!), then we live in a flat Universe that will keep expanding forever, but if not then we don't know yet.
- Understanding dark energy is one of the biggest questions for humankind today.
- There are many experiments underway to accomplish this. So we have to wait and see.
- But what are the options?



The Distant Future: The Big Rip

- Although this is not very popular, and the chances of it occurring is small, what if Dark Energy is not a cosmological constant?
- One extreme case is that it gets carried away, and rips the Universe apart.



  - If repulsive force increases– Brooklyn may expand too.
  - Gravity/E&M forces can not hold Galaxies rip apart
  - Could rip the MilkyWay apart in ~1-100 billion years
  - Earth gets ripped apart soon after
  - You'd get ripped apart!

http://www.youtube.com/watch?v=oGVYG0ce1Ps