Astronomy 330

This class (Lecture 5):

The End of the Universe

Next Class:

Molecular Clouds

Presentation Synopsis due Thursday!

Music: *Across The Universe* – The Beatles

Outline

- The probable fate of the Universe
- Everything depends on Dark Energy
- Star Formation.. today….

The Universe

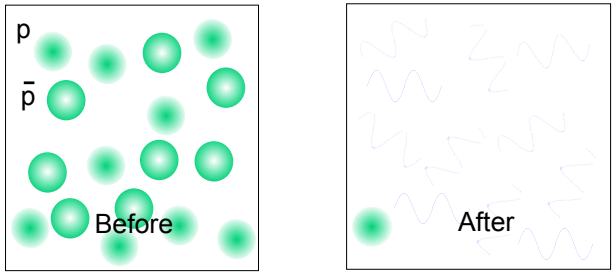
- Began with a Big Bang
  - 13.7 billion years ago
- Still expanding and cooling
  - The rate of expansion is known
- It is BIG
  - As far as we are concerned, it is infinite in any direction
- The universe is homogeneous and isotropic
  - **Homogeneous** - The same "stuff" everywhere
  - **Isotropic** - 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

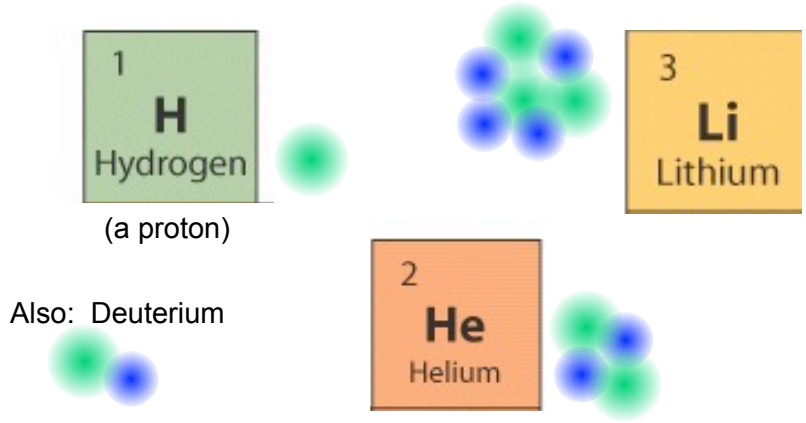
Annihilation of the Anti-matter

- 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)**

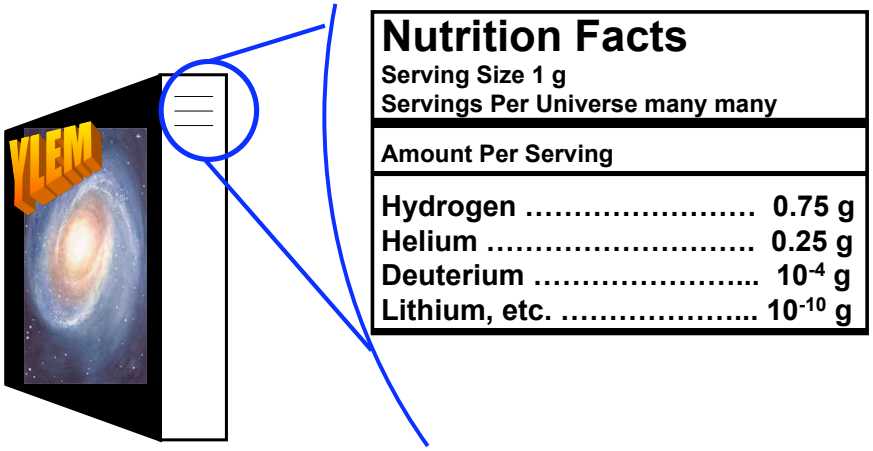


Big Bang Nucleosynthesis

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.

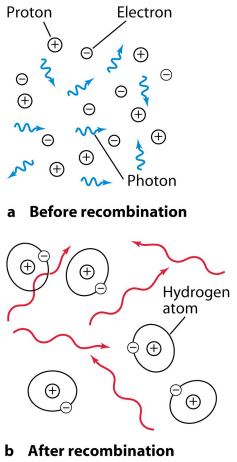


End Result: Big Bang Correctly Predicts Abundances



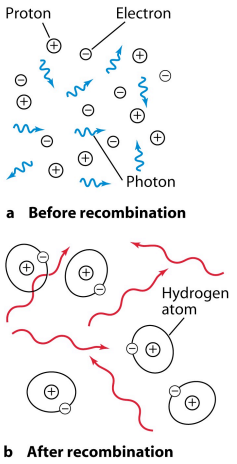
Era of Recombination

- 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



Era of Recombination

- Once the Universe is transparent, this light can travel across the Universe
- This light is the source of the Cosmic Microwave Background!
- **The first H atoms in the Universe!**

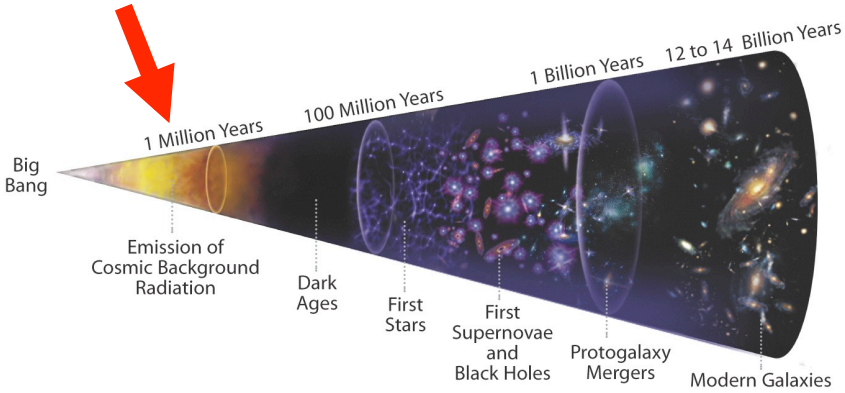


Question

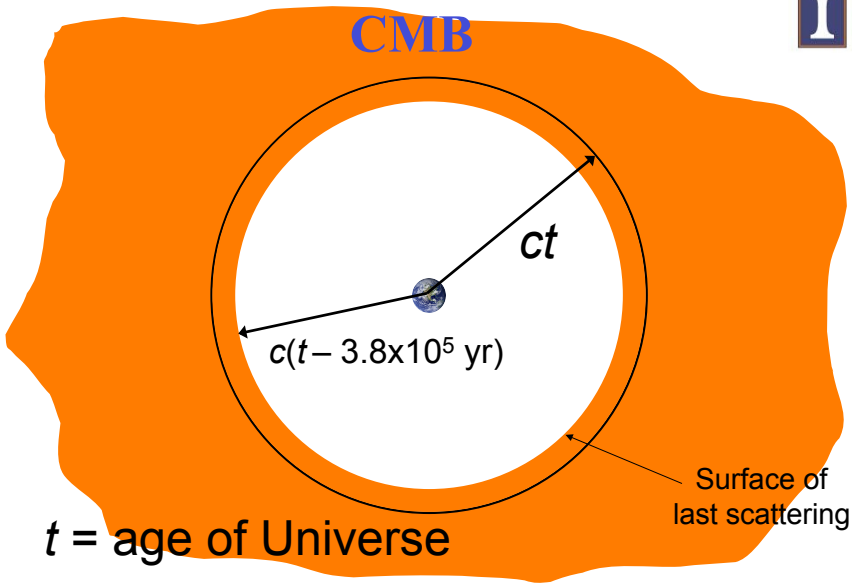
How did Hydrogen first appear in the Universe?

a) When the Universe cooled and quarks combined to form the first protons, eventually gaining an electron.
b) When the Universe cooled and the melted protons reformed, eventually gaining an electron.
c) When the Universe cooled and the antimatter turned into matter, eventually gaining an electron.
d) When the Universe cooled and the hydrogen atoms fused into helium atoms, eventually gaining an electron.
e) They always existed.

Origin of the CMB



Looking Back in Time to the CMB

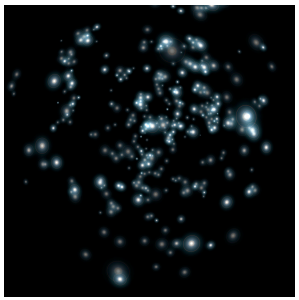


- After recombination came a period known as the Dark Ages
  - 380,000 to 200 million years
  - No light yet detected from this period
- Matter consists of warm clouds of hydrogen and helium
  - Too hot for star formation to occur
  - Gravity slowing drawing clouds together into bigger and bigger clumps
  - Proto-galaxies

http://www.darkages.com/

The First Stars

- From the initial seeds of the Big Bang, our local group of proto-galaxies are clumps of hydrogen and helium.
- Proto-galactic clouds are still slowly collapsing – no galaxies yet



http://www.blackshoals.net/ImageBank/gallery/gallery/huge/The-first-stars-clustering.jpg

The First Stars

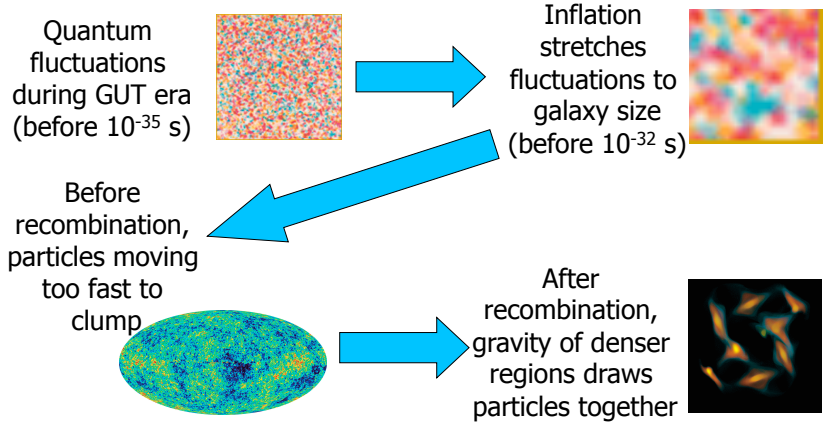
- These clouds cool.
- The first stars began to form after about 200 million years after the Big Bang
- Remember mostly hydrogen gas with very few metals.

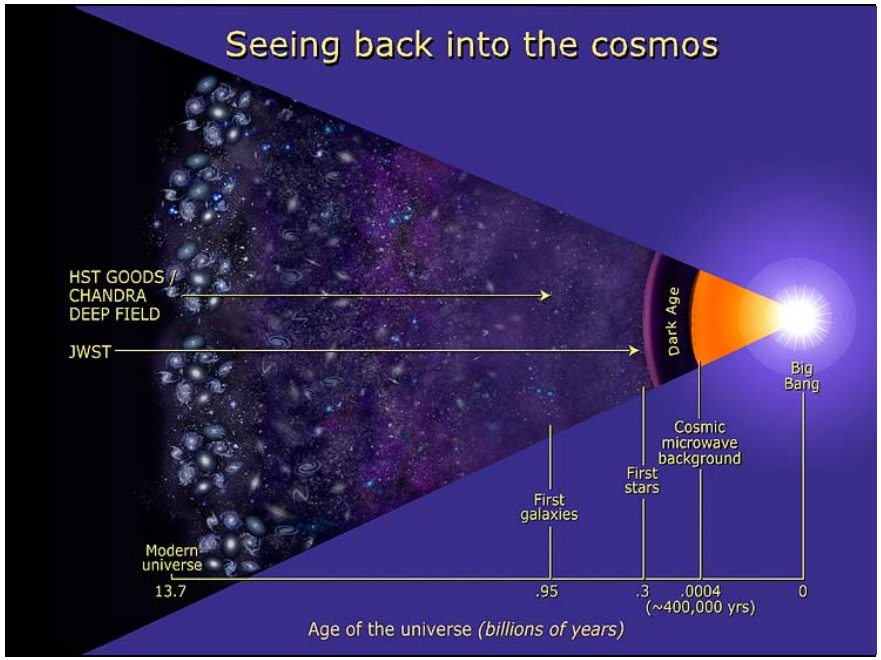
Question

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

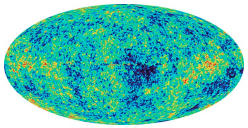
Top 3 Reasons We Believe in the Big Bang

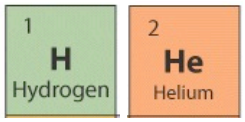
1. Cosmic Microwave Background
   - Big Bang working at about 380,000 yrs
   - Tiny fluctuations: "seeds" of galaxies
2. Big Bang Nucleosynthesis
   - H and (almost all) He come from the Big Bang
   - Big Bang working at 1 sec
3. The Hubble Law: $v=H_0 d$

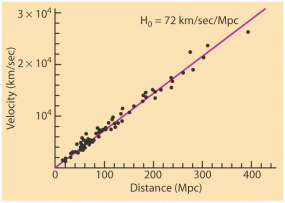
   + Einstein's General Relativity

   = Expanding Universe with an age of 13.7 billion yrs

One of the most successful scientific theories of all time!







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

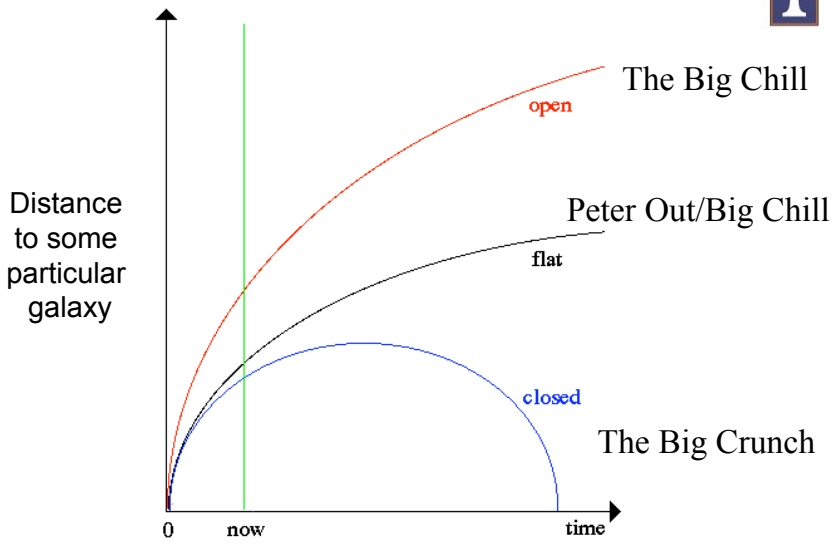
Both are observable!

or

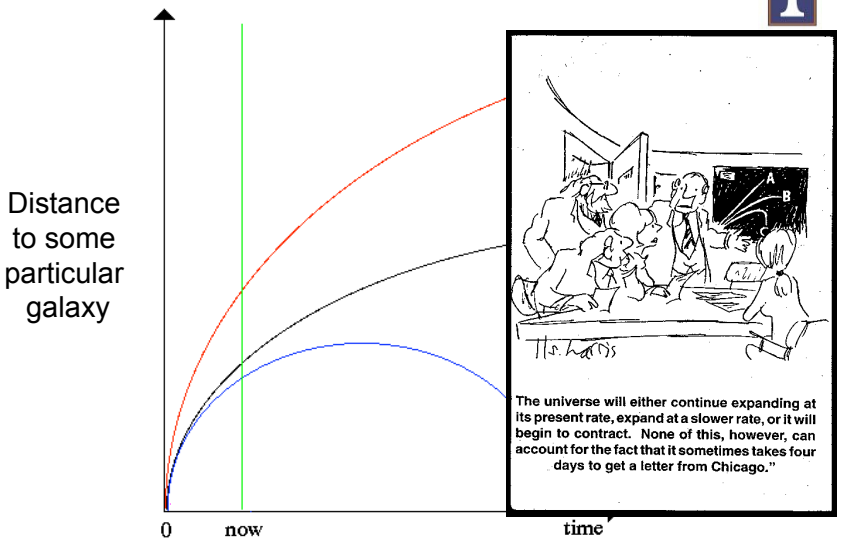
Our fate is a **quantitative** question :

- **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

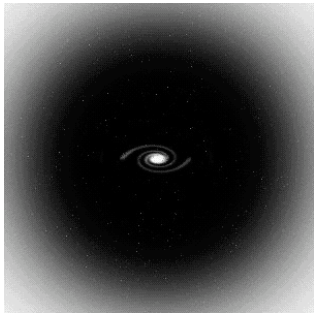
Our Universe could be one of three types: Open, Closed, or Flat. What would happen to a closed Universe?

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.

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

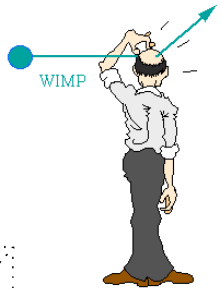


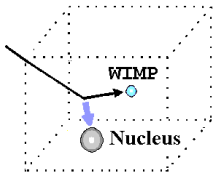
- The unseen mass in our Galaxy!
- Needed to explain stellar orbits.
- The dark matter in the Galaxy is in greatly extended halo
  - Up to 90% of the Galaxy's mass is dark matter!
- Most of our Milky Way is Dark Matter
  - We can't see it (only interacts via gravity)
  - We aren't sure what it is, but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

How Much Do We Weigh?

% of mass for closed Universe

22% Dark matter
Needed to explain:
galaxy rotation curves
clusters of galaxies

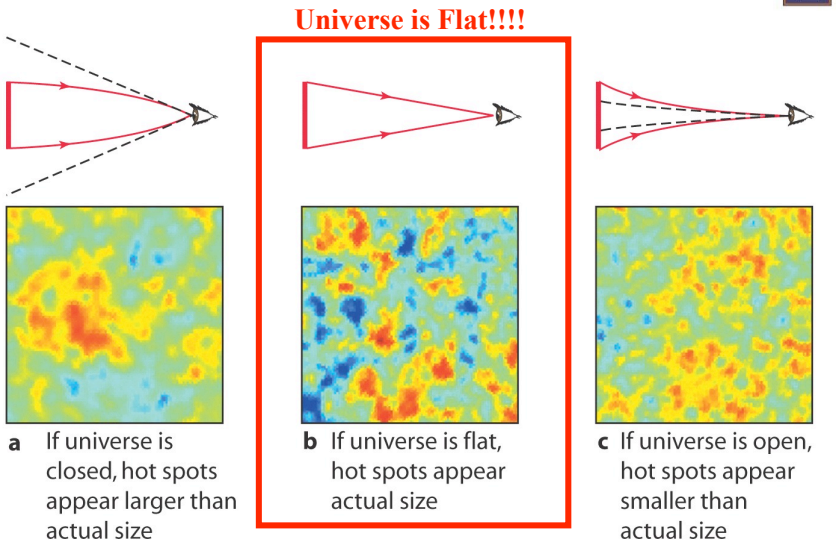
4.5% Ordinary matter
Made of protons, neutrons, and electrons

<1.5% Neutrinos

28% Total Not enough to close the Universe

So we live in an open Universe?

CMB Measurements



Peter Out/ Big Chill

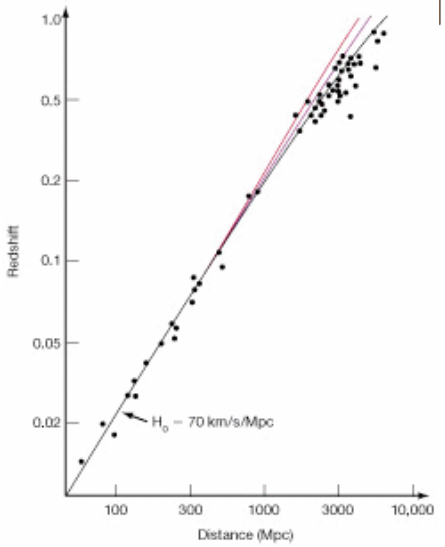
- The Universe will just barely expand forever, getting cooler and cooler.
- But if all of the mass, dark +regular, isn't enough, **then what's up**?
- The fate of the Universe is really dependent on the amount of matter and energy in the Universe
  → $E = mc^2$

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!

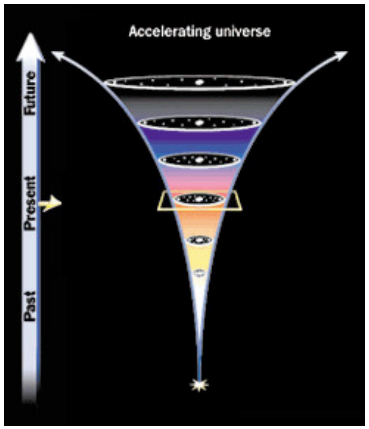
It's as if there's another force pushing the universe apart – a Cosmological Constant!!!

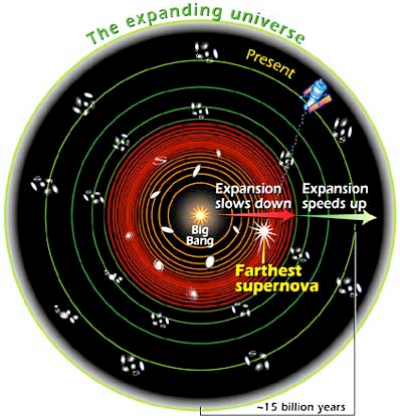


Dark Energy

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

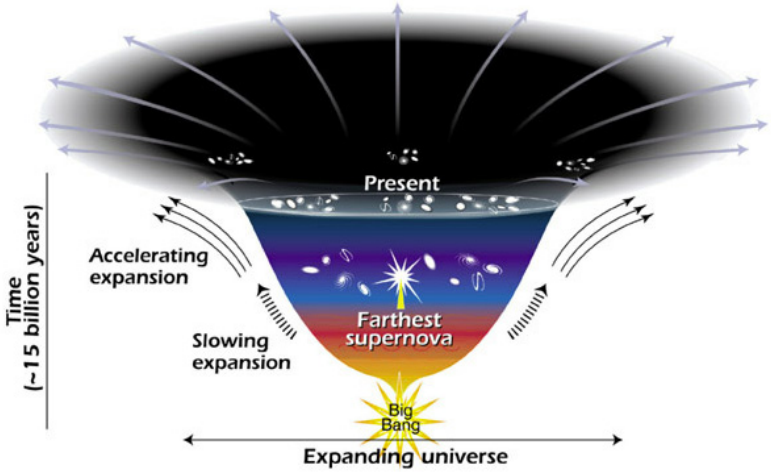
The Accelerating Universe!!!





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

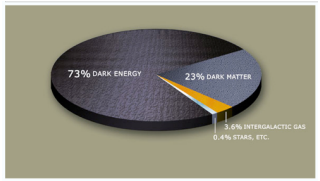
Question

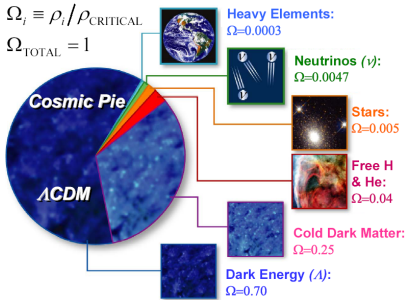
Based on measurement of the CMB, we live in a flat Universe. But there is not enough known mass to account for this. What's up?

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.

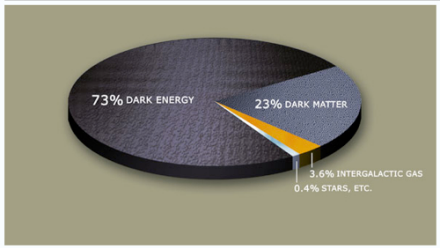




Dark Energy even dwarfs dark matter! Regular matter is really insignificant. We *really* don't know anything about what's going on!!

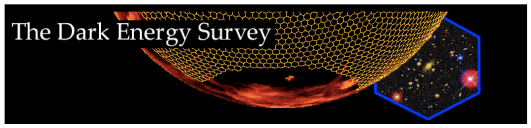
The Accelerating Universe!!!

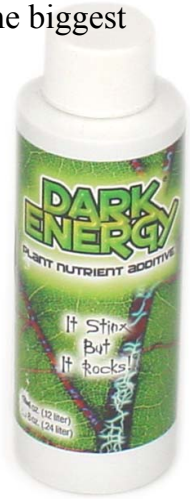
- But, we are still in very speculative times here.
- How the Universe ends will depend on the nature of Dark Energy.
- If it really acts like a cosmological constant (go Einstein!), then we live in a flat Universe that will keep expanding forever, but if not then we don't know yet.



The Accelerating Universe!!!

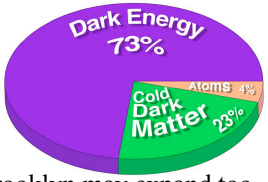
- Understanding dark energy is one of the biggest questions for humankind today.
- There are many experiments underway to accomplish this. So we have to wait and see.
- But what are the options?





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.

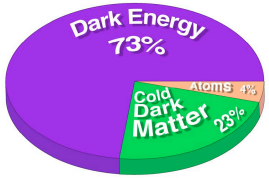


  - If repulsive force increases– Brooklyn may expand too.
  - Gravity/E&M forces can not hold Galaxies rip apart
  - Could rip the Milky Way apart in ~1-100 billion years
  - Earth gets ripped apart soon after
  - You'd get ripped apart!

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

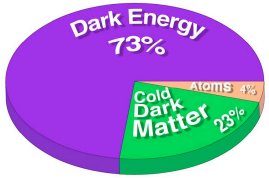
The Distant Future: The Big Crunch

- Another extreme case, is if the nature of Dark Energy changes and we re-collapse afterall.
- The entire Universe falls back to a point.
- All atoms smashed into particles, then pure energy—very hot again.
- Perhaps this has happened before?
- Would take more than 14 billion years.



The Distant Future: The Big Chill

- From what we know right now, we think that the Peter Out/Big Chill is more likely.
- It is less exciting and slow, but an effective way to end the human race.
- We'll talk about this later, when we discuss the lifetime of a civilization…



The Early Universe?

- So, in the early Universe, the first elements formed were mostly Hydrogen (75%) and Helium (25%) by mass. What does that mean for life in the early Universe?

- Globular clusters contain the oldest stars in the Milky Way– about 10 to 13 billion years old. Should we look for life around these stars?

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

What is the Earth made of?

- Very little hydrogen and helium. They make up less than 0.1% of the mass of the Earth.
- Life on Earth does not require any helium and only small amounts of non-H_2O hydrogen.
- These are post-Big Bang!

What is the Earth made of?

- Life's Elements were actually forged inside of stars!
- ONC was formed in stars. That means 2nd or 3rd or nth generation of stars are required before life can really get going. These elements were not originally formed in the Big Bang.
- **"We are star stuff!"**
- How did that come about?

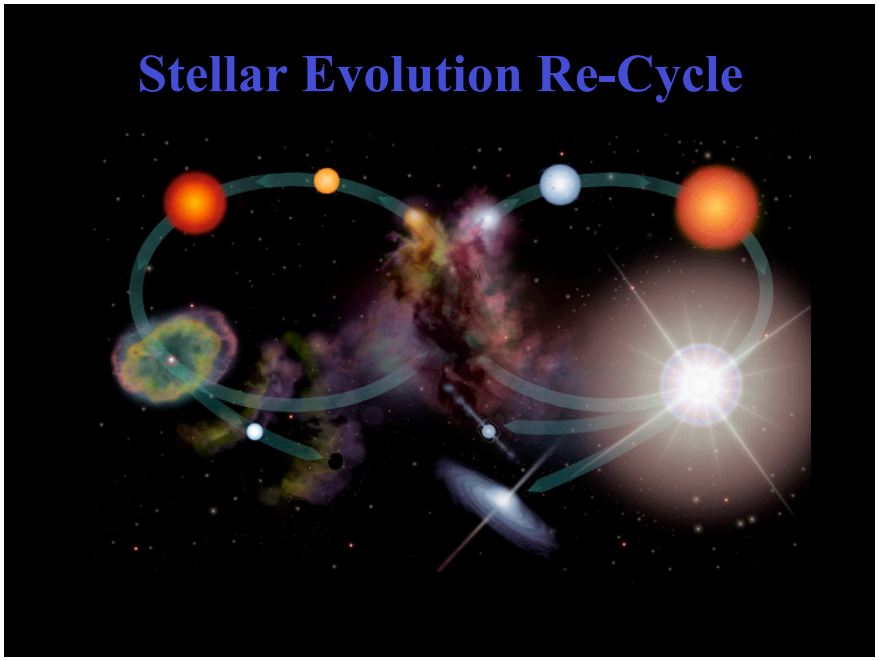
What are Galaxies?

- They are really giant re-cycling plants separated by **large** distances.
- Stars are born in galaxies out of dust and gas.
- Stars turn hydrogen into helium, then into heavier elements through fusion for millions or billions of years.

What are Galaxies?

- Stars die and eject material back into the galaxy.
- New stars are formed.
- And so on.
- Crucial to the development of life!
- Let's spend some time talking about star formation today to get a handle on star formation in the Universe.

Stellar Evolution Re-Cycle



The Interstellar Medium (ISM)

- Stuff between the stars in a galaxy.
- Sounds sort of boring, but
  - Actually very important
  - Features complex physical processes hidden in safe dust clouds

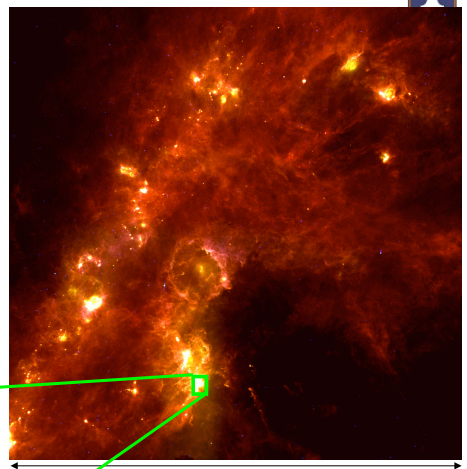
- Every star and planet, and maybe the molecules that led to life, were formed in the dust and gas of clouds.

- Exists as either
  - Diffuse Interstellar Clouds
  - Molecular Clouds

Keyhole Nebula

Giant Molecular Clouds

- Cool: < 100 K
- Dense: $10^2 - 10^5$ H_2 molecules/cm^3
  (still less dense than our best vacuum)
- Huge: 30 – 300 lyrs across, $10^5 - 10^6$ solar masses
- CO molecular emission & dust emission trace structure



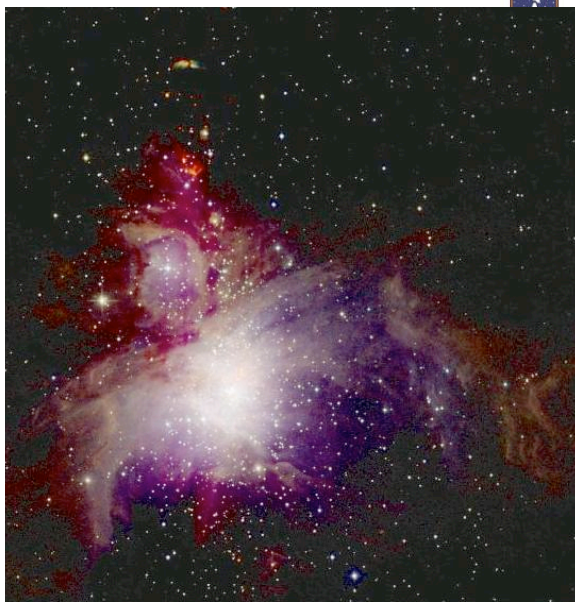
100 degrees

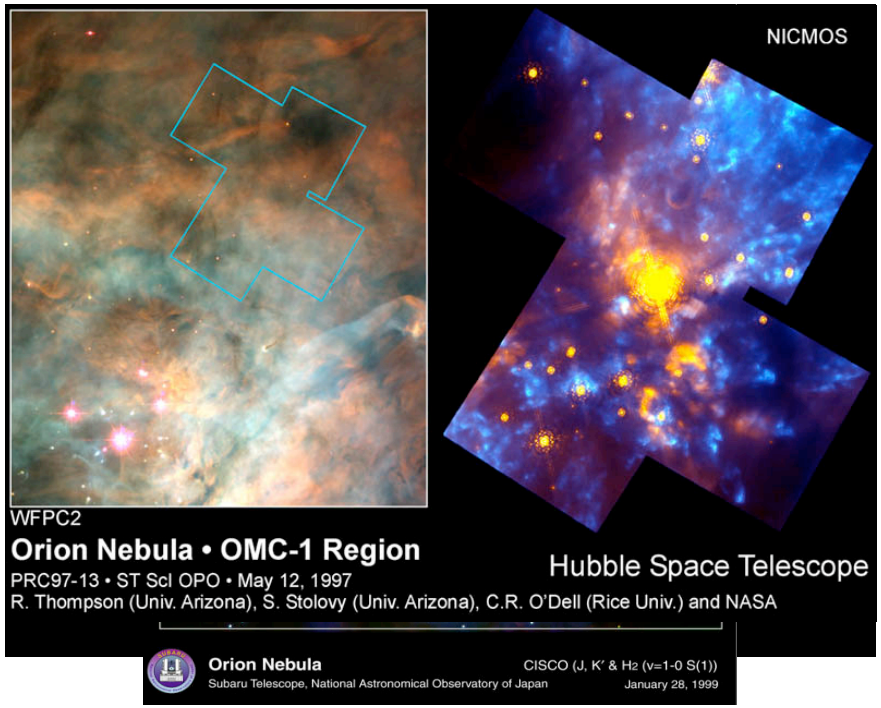
Infrared image from *IRAS*

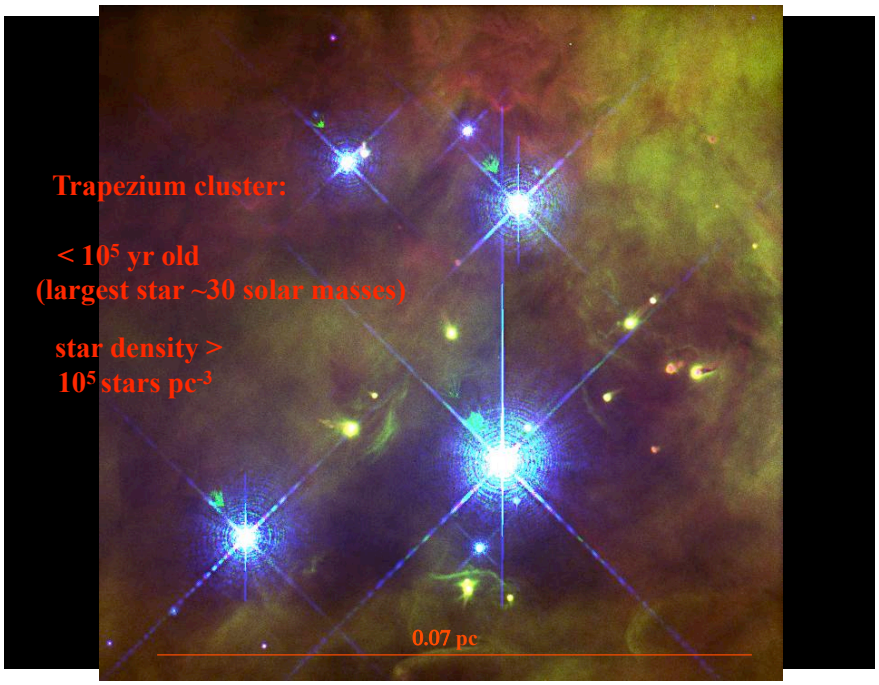
Orion Nebula

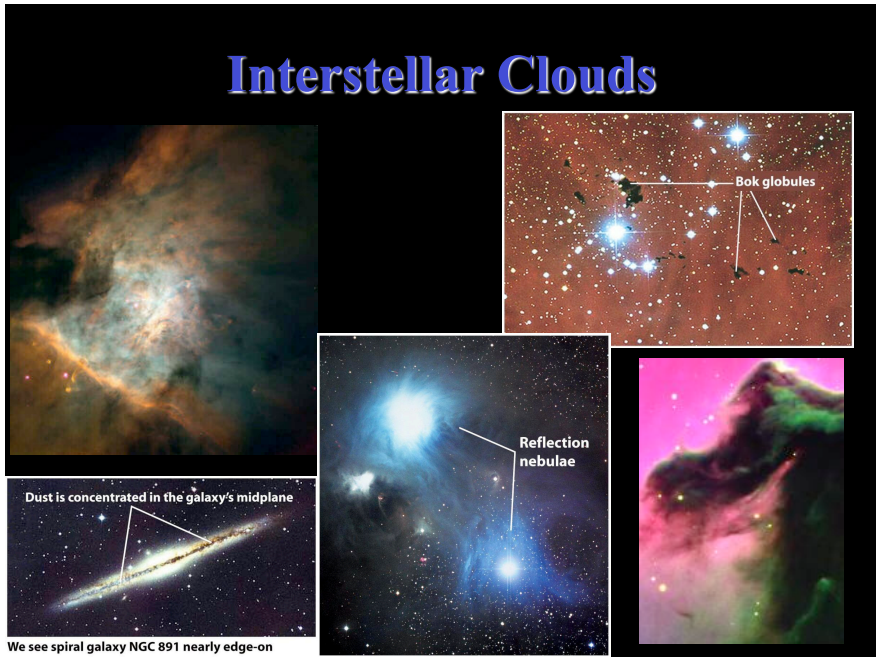
(near infrared)

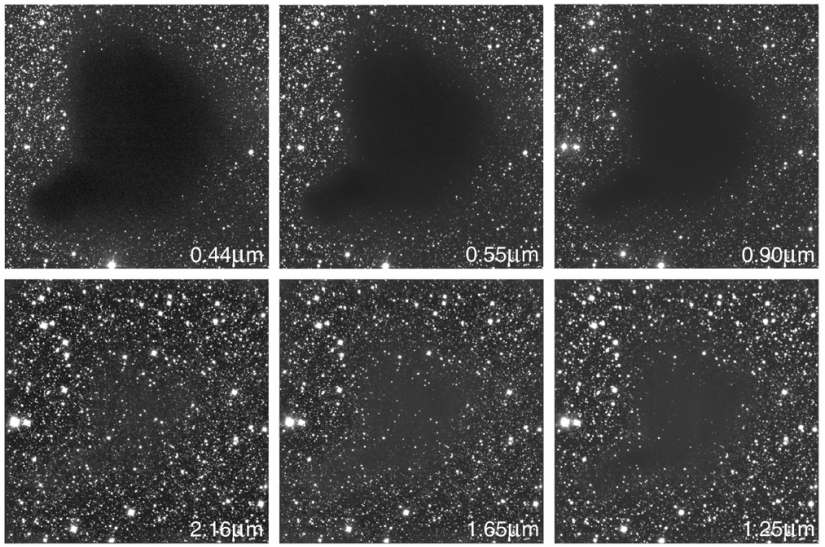
Nearest massive star forming region with a large molecular cloud associated (distance of 1500 lys)











The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

ESO PR Photo 29b/99 (2 July 1999)