Top Ten Signs
Your Astronomy Professor May Be Nuts
(based on Lee Carkner List)

10) The title of every lecture is: "Man, Them Stars is Hot!".
9) His so-called "telescopes" are really just paper towel rolls covered in aluminum foil.
8) To illustrate the vastness of the universe, he makes everybody walk to Springfield.
7) Thinks he's married to the slide remote.
6) Your grade is based entirely on how many ping-pong balls you can fit in your mouth.
5) His so-called Drake Equation video is really just an old episode of Alf.
4) He makes everyone wear a soup pot on their head to protect the class from "Klingon mind control lasers".
3) About 90% of all classes involve dressing monkeys up to look like Frank Drake.
2) When you go to his office hours, he is always hiding under the desk so that the "space squirrels" can't get him.
1) The only observing advice he ever gives is, "Keep an eye out for the mothership."

Astronomy 330

This class (Lecture 5):

From Atoms to Molecules to Clouds

Next Class:

Star Formation

Presentation Synopsis due Sunday.

Music: *Under the Milky Way* – The Church

Drake Equation HW #1 Result

= 150

N =

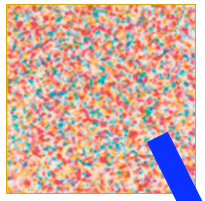
# of advanced civilizations we can contact in our Galaxy today

Outline

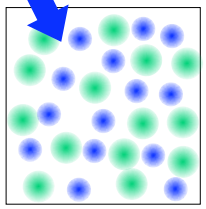
- The early Universe– The origin of H
- The probable fate of the Universe
- Everything depends on Dark Energy

Quark Confinement

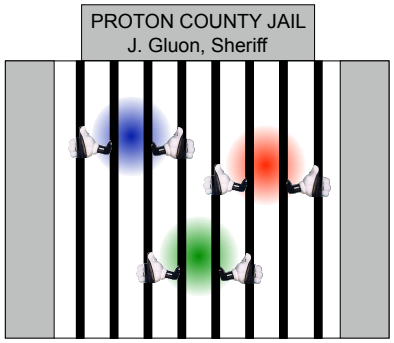
- 10^{-6} seconds: free quarks condensed into protons and neutrons



Before
Free quarks



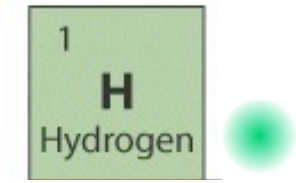
After
Protons
and
neutrons



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

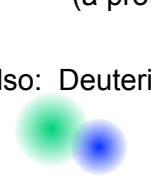
Big Bang Nucleosynthesis

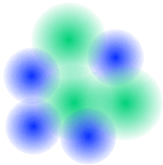
When the Universe was 1 sec to 3 mins old, the temperature fell to 10^9 K and protons and neutrons can "shack-up" to form the first light elements.

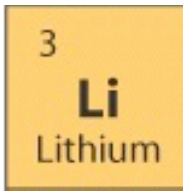


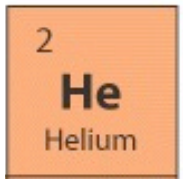
(a proton)

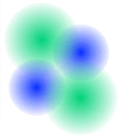
Also: Deuterium



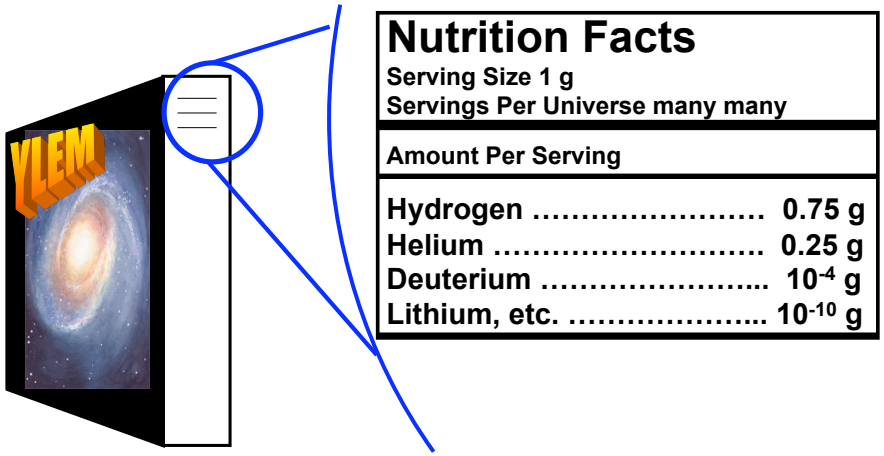








End Result:
Big Bang Correctly Predicts Abundances



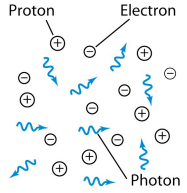
Nutrition Facts
Serving Size 1 g
Servings Per Universe many many

Amount Per Serving

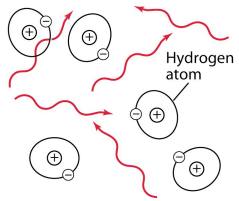
Hydrogen	**0.75 g**
Helium	**0.25 g**
Deuterium	**10^{-4} g**
Lithium, etc.	**10^{-10} g**

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 first H atoms proper!**



a Before recombination



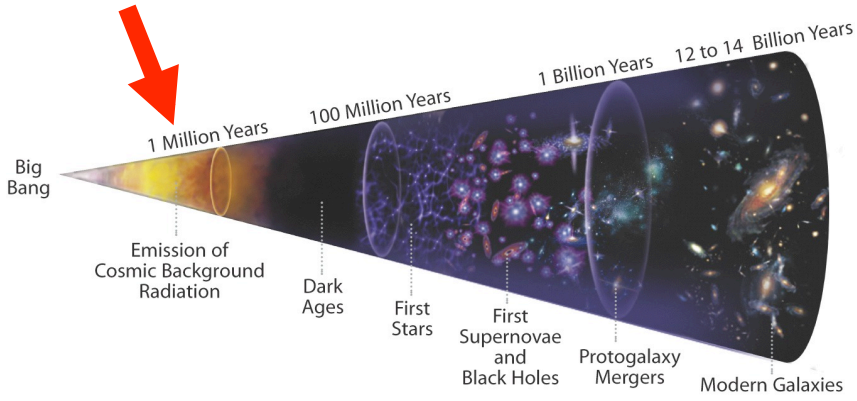
b After recombination

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



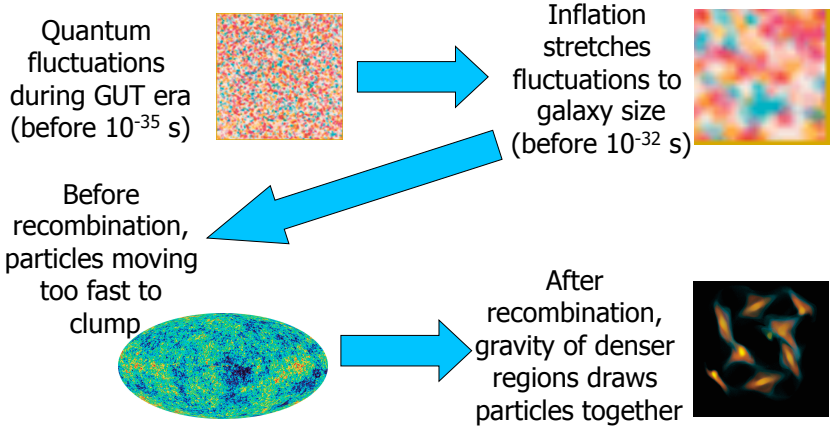
- After recombination came a period known as the Dark Ages
  - 500,000 to 100 million years
  - No light yet detected from this period
- Matter consists of warm clouds of hydrogen and helium
  - Too hot for star formation to occur
  - Gravity slowing drawing clouds together into bigger and bigger clumps
  - Proto-galaxies

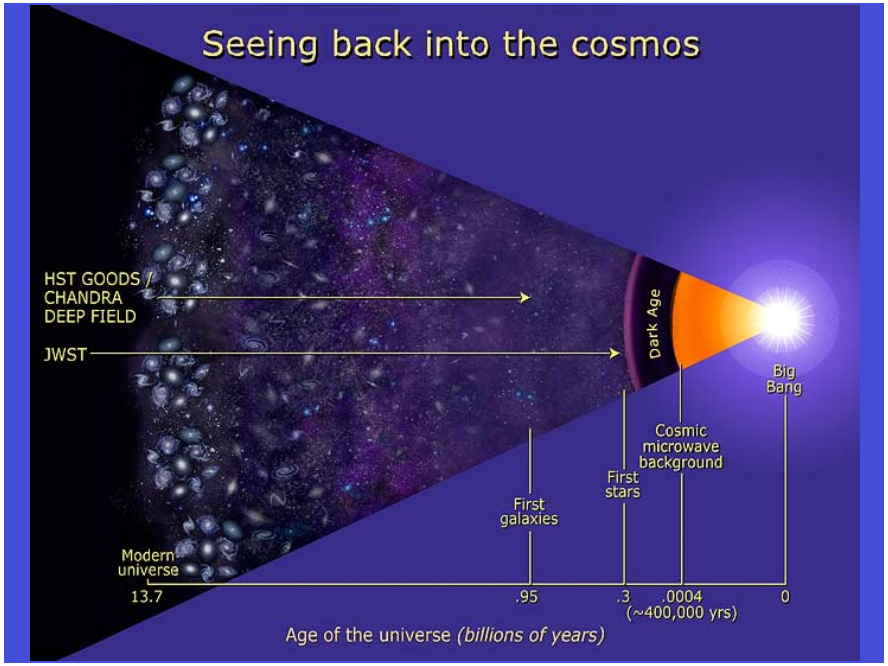
http://www.darkages.com/

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.

The Beginnings of Galaxies





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.

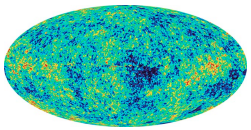
From the Home Office in Urbana, IL

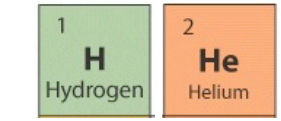
Top 3 Reasons We Believe in the Big Bang

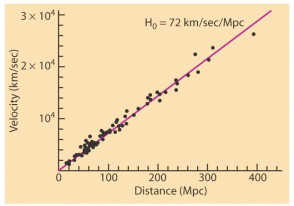
1. Cosmic Microwave Background
   - Big Bang working at about 500,000 yrs
   - Tiny fluctuations: "seeds" of galaxies
2. Big Bang Nucleosynthesis
   - H and (almost all) He come from the Big Bang
   - Big Bang working at 1 sec
3. The Hubble Law: $v=H_0 d$

   + 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

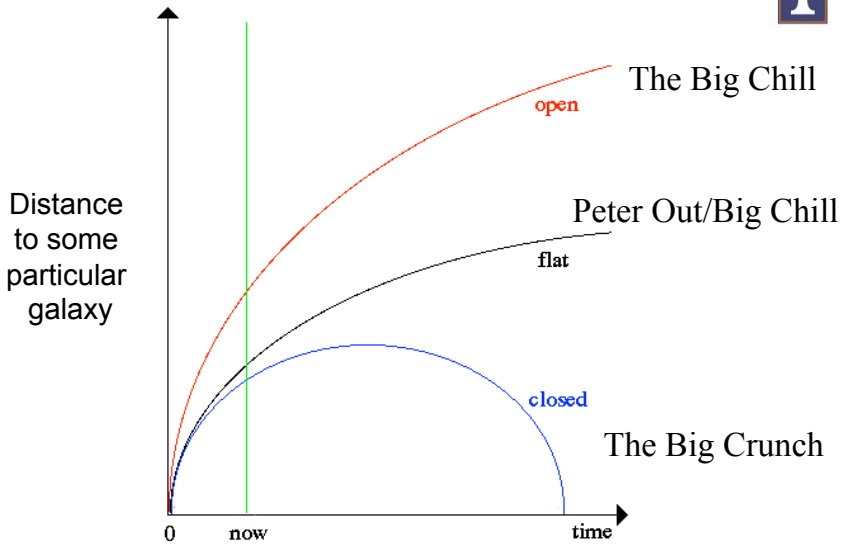
Both are observable!

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.**

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

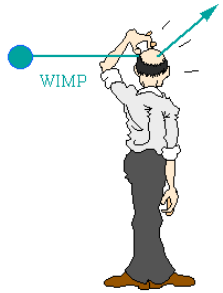
Our Universe could be one of three types: Open, Closed, or Flat. What would happen to a closed Universe?

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

- The Universe is dominated by Dark Matter, probably some heavy exotic particle created during the Big Bang. (Weakly Interacting Massive Particle– WIMPs?).
- One way that we know this comes from the rotation curves of Galaxies. We can't see dark matter, but we can see the influence of it.
- It turns out that 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"

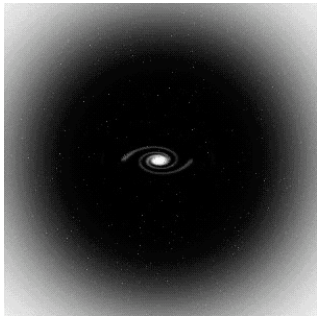
How to search for WIMPs?



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

Dark Matter

- The dark matter in the Galaxy is in greatly extended halo
  - Up to 90% of the Galaxy's mass is dark matter!
  - Galaxy may have over a trillion solar masses total!



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

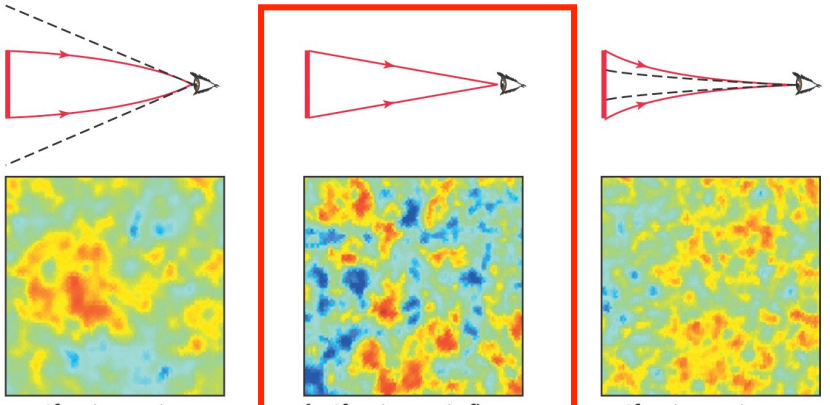
<1.5% Neutrinos

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

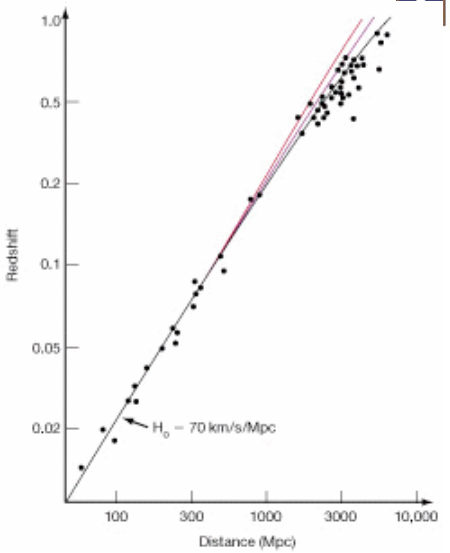
- The Universe will just barely expand forever, getting cooler and cooler.
- If all of the mass, dark+regular, isn't enough, **then what's up**?
- The fate of the Universe is really dependent on the amount of matter and energy in the Universe → $E = mc^2$

We must be missing some extra mass/ energy?

The Accelerating Universe!!!

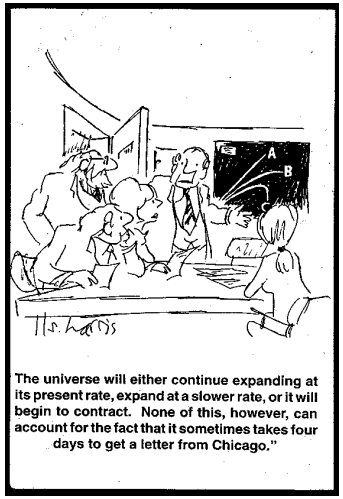
The universe is not slowing down at all. In fact, it's speeding up!!! We live in an accelerating universe!

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

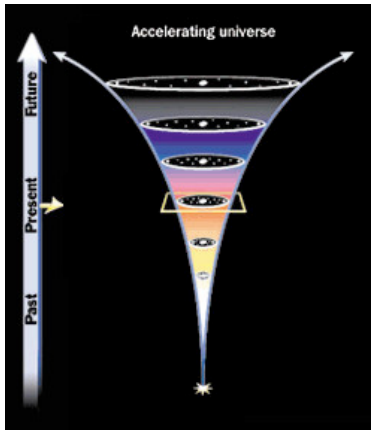


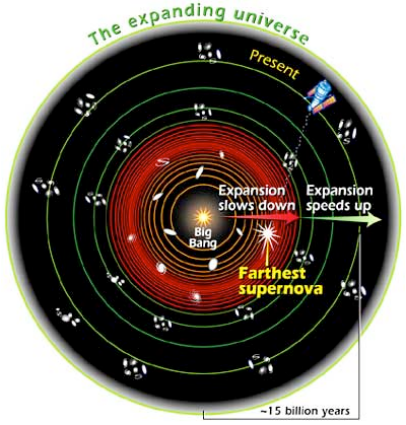
Dark Energy

- 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
- Dark energy is actually *accelerating* the expansion of the Universe!



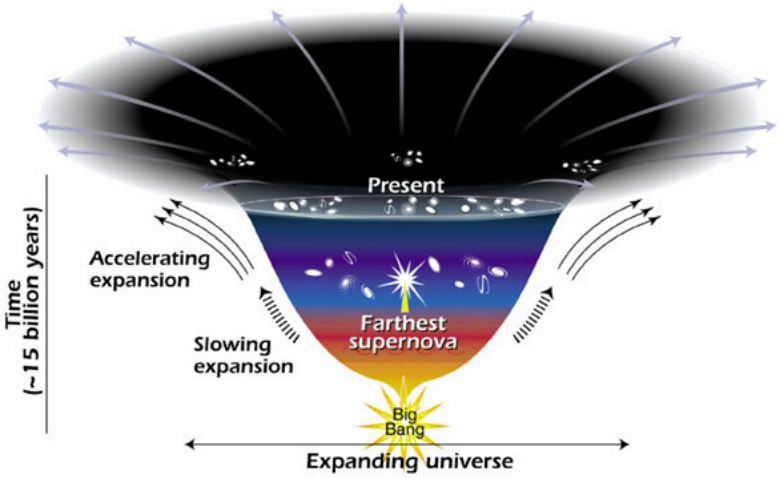
The Accelerating Universe!!!





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.

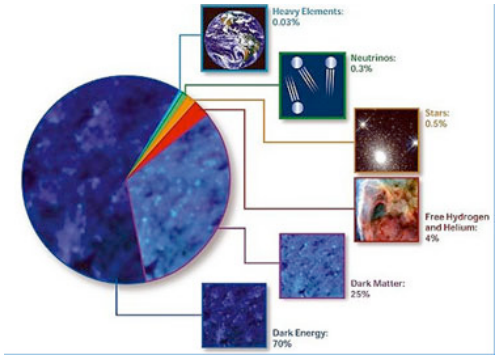
Effects of Dark Energy



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

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!!

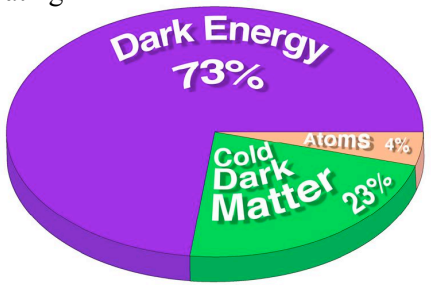
Question

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 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
  - The 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 or nowhere!

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.
- All of these elements must be formed in stars. That means 2^{nd} or 3^{rd} or n^{th} 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!

Stellar Evolution Re-Cycle