Astronomy 230

Section 1– MWF 1400-1450
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Office Hours:
MTF 10:30-11:30 a.m. or by appointment

This Class (Lecture 4):

The Early Galaxy and the First Stars

Next Class:

From Atoms to Molecules

HW1 due on Friday.

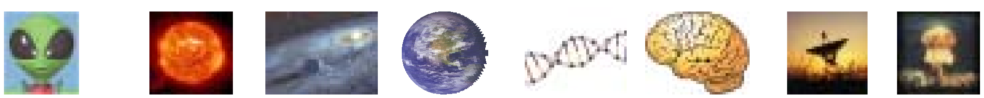
Music: *Sonne* – Rammstein

Outline

- Top 3 Reasons we believe in the Big Bang Theory.
- The fate of the Universe.
- Implications for early life.
- The early Galaxy and the First Stars
- Hydrostatic Equilibrium of Stars
- 4 Fundamental Forces
- Nuclear Fusion

Drake Equation

Frank Drake



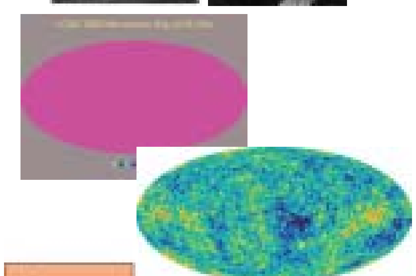
$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Rate of formation of Sun-like stars	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	stars/ yr	systems/ star	planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

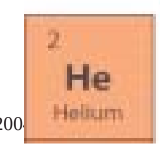
From the Home Office in Urbana, IL
Top 3 Reasons We Believe in the Big Bang

3. Hubble: v=HR
   + Einstein General Relativity
   = Big Bang and expanding Universe
   with age t = 13.7 billion yrs

2. Cosmic microwave background
   Primordial fireball– Big Bang working at t = 400,000 yrs
   - Nearly uniform temperature in all directions early Universe was very homogeneous
   - Tiny temperature fluctuations: "seeds" of galaxies



1. Big Bang Nucleosynthesis
   H and (almost all) He come from Big Bang
   Big Bang model working at t = 1 s



What is the Universe's Fate?

Today: Universe is expanding. What happens 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

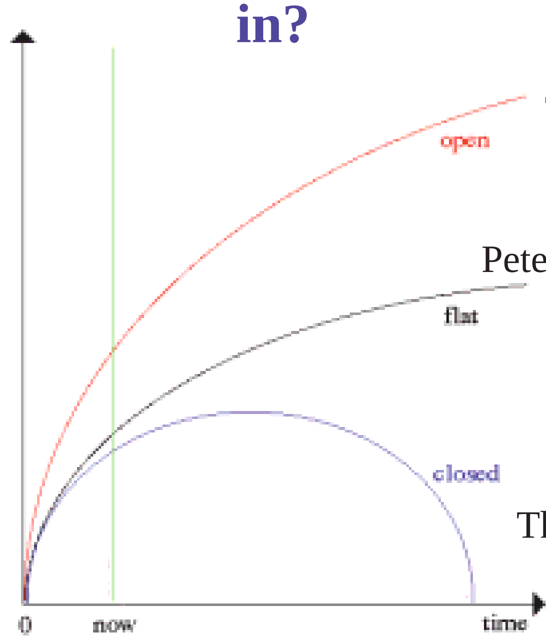
Both are observable!

Our fate is a **quantitative** question :

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

What kind of Universe do we live in?

Distance to some particular galaxy



The Big Chill

Peter Out/Big Chill

The Big Crunch

How Much Do We Weigh?

% of critical <u>mass</u>

22% Dark matter

Needed to explain:
galaxy rotation curves
clusters of galaxies

4.5% Ordinary matter

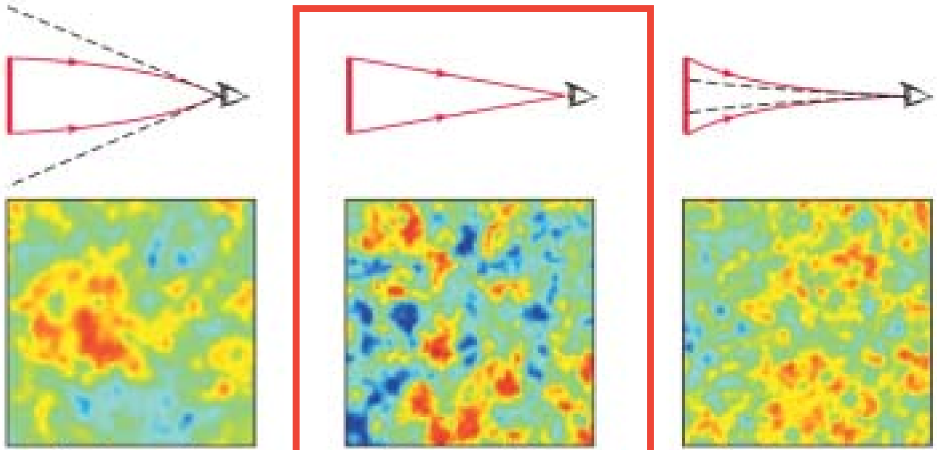
Made of protons, neutrons, and electrons

<1.5% Neutrinos

28% Total <u>Not enough to close the Universe</u>

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 there is something else afoot.
- The fate of the Universe is really dependent on the amount of matter and energy in the Universe. $E = mc^2$
- So, a new type of energy called Dark Energy (repulsive gravity and not related to Dark Matter) exists. The dark energy is dominating the fate of the Universe.
- 70% of the Universe is this dark energy.

The Early Universe?

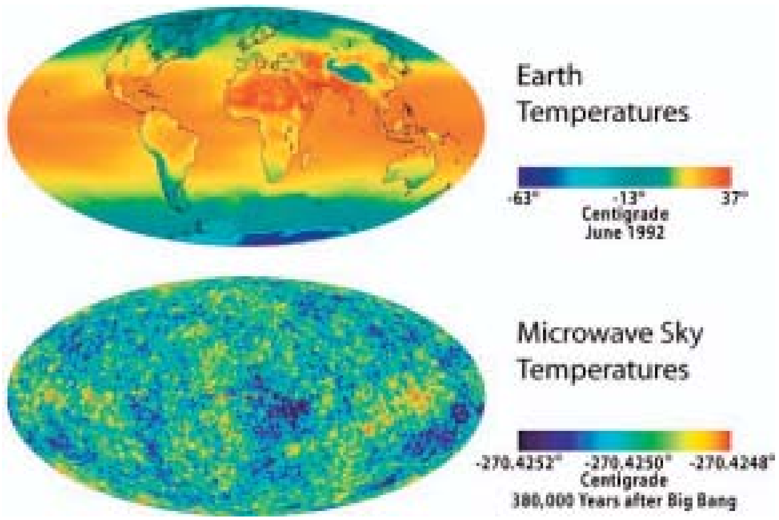
- So, in the early Universe, the first elements formed were mostly Hydrogen (75%) and Helium (25%) by mass. What does that mean for life in the early Universe?
- Globular clusters contain the oldest stars in the Milky Way– about 10 to 13 billion years old. Should we look for life around these stars?

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 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?

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

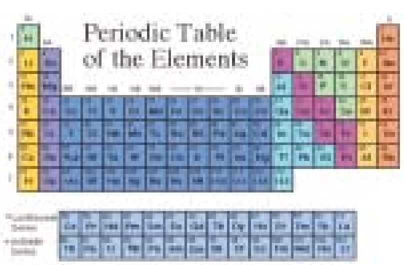


What are Galaxies?

- They are really giant re-cycling plants separated by **large** distances.
- Stars are born only in galaxies out of dust and gas.
- Stars turn hydrogen into helium, then into heavier elements through fusion for millions or billions of years.
- Stars die and eject material back into the galaxy.
- New stars are formed.
- And so on.
- Crucial to the development of life!

Chemical Basis for Life

- The average human has:
  - 6 x 10^{27} atoms (some stable some radioactive)
  - During our life, 10^{12} atoms of Carbon 14 (^{14}C) in our bodies decay.
  - Of the 90 stable elements, about 27 are essential for life. (The elements from the Big Bang are not enough!)



http://www.genesismission.org/science/mod2_aei/

Chemical Basis for Life

By Number…

- Life on Earth is mostly:
  - 60% hydrogen
  - 25% oxygen
  - 10% carbon
  - 2% nitrogen
  - With some trace amounts of calcium, phosphorous, and sulfur.
- – The Earth's crust is mostly:
  - 47% oxygen
  - 28% silicon

- The Universe and Solar System are mostly:
  - 93% hydrogen
  - 6% helium
  - 0.06% oxygen
  - 0.03% carbon
  - 0.01% nitrogen

Galaxies for you and me

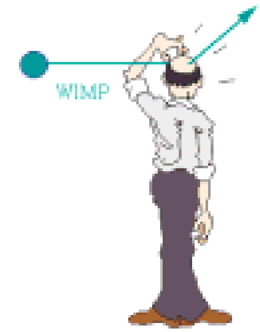
- Life as we know it, needs more elements than the Big Bang could provide.
- Composition of life is unique.
- Does the environment of the Galaxy nourish life?
- At the vary least we need galaxies to process the material from the Big Bang into materials that life can use.
- How did galaxies form?

http://www.chromosome.com/lifeDNA.html

The Early Galaxies

- 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.
- The normal matter flocks to the dark matter due to gravity. These initial seeds of galaxies and galaxy clusters are the original mix of elements– 75% hydrogen and 25% helium (by mass).

How to search for WIMPs?

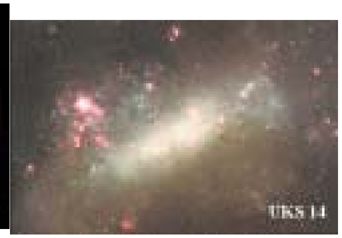


http://www.shef.ac.uk/physics/research/pa/DM-introduction-0397.html

Remember that the Milky Way is Not Alone?

We have a few orbiting galaxies that are gravitationally bound the Milky Way.

Canis Major (42,000 ly away)

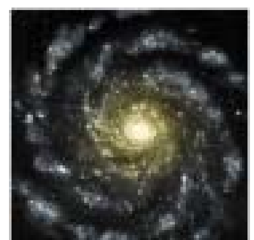


Large Magellanic Cloud (180,000 ly away)

Sagittarius Dwarf Elliptical (80,000 ly away)

Small Magellanic Cloud (250,000 ly away)

And Many Galaxies in the Local Group



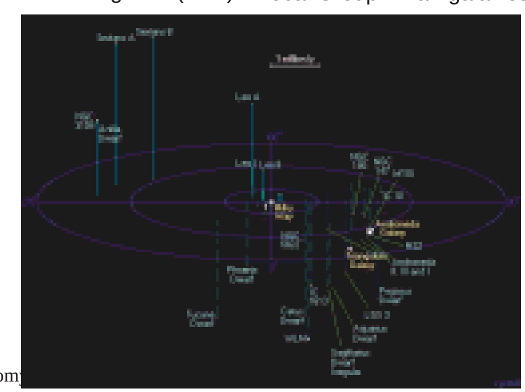
Milky Way

2 MLyrs

Andromeda (M31)

Triangulum (M33)

Local Group Dwarf galaxies



The First Stars

- From the initial seeds of the Big Bang, our local group of galaxies probably broke into clumps of hydrogen and helium.
- We'll look at star formation in detail latter, but let's think of the first star to form in our Milky Way
- May have formed as early as 200 million years after the Big Bang.
- Probably more massive than stars today, so lived quickly and died quickly.
- What happened? Why did this "raw" gas form anything?

Water Power?

- Does a bottle of water have any stored energy? Can it do work?

Gas powered

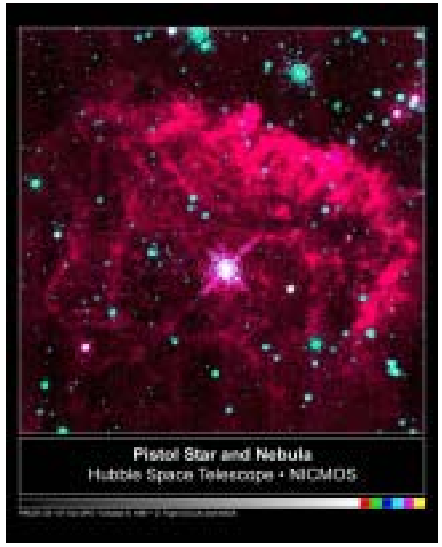
- Similar to my bottle of water, these initial gas clumps want to reach the center of their clump-ness.
- The center gets hotter and hotter. The gravitational energy potential turns into heat (same as velocity actually).
- It is a run-away feature, the more mass at the center, the more mass that wants to be at the center.
- The center of these clumps gets hotter and denser.

Cooking with Gas

- For the first time, since 1-month after the Big Bang, the centers of the clumps get above 10^7 K.
- That is hot enough for nuclear fusion to occur. If that had not happened, life would never have existed.
- But are things different than what we learned in Astro 100? These are the First Stars after all.

The Most Massive Star in the Milky Way Today

- The Pistol star near the Galactic center started as massive as 200 solar masses.
- Releases as much energy in 6 seconds as the Sun in a year.
- But it blows off a significant fraction of its outer layers.
- How did the first stars stay so massive?
- Perhaps they are slightly different than this case?

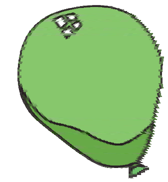


http://www.u.arizona.edu/~justin/images/hubblepics/full/PistolStarandNebula.jpg

Pressure

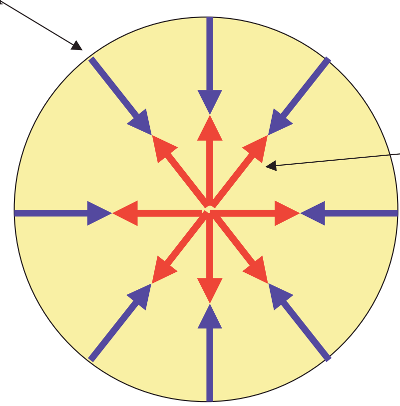
- What is pressure?
  - Pressure $= \frac{Force}{Area}$
- Explain blowing up a balloon?
- http://www.phy.ntnu.edu.tw/java/idealGas/idealGas.html

Pressure of Earth's atmosphere is 14.7 pounds per square inch



The Battle between Gravity and Pressure

Gravity pushes in

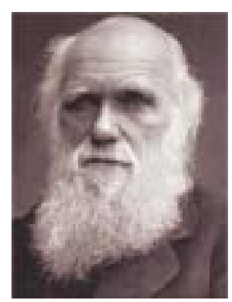


The heat pressure must push out.

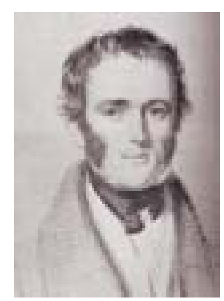
Hydrostatic equilibrium

What Holds Up the Sun?

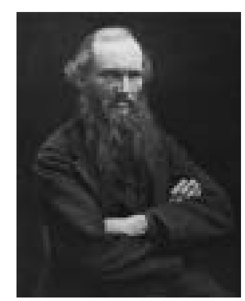
- Without an energy source, the Sun would rapidly cool & contract
- Mid-1800s:
  - Darwin: evolution needs Sun & Earth to be > 10^8 years old
  - Lyell: geological changes also needs > 10^8 years
  - Kelvin: gravitational heating gives only a few million years!
- No physical process then known would work!



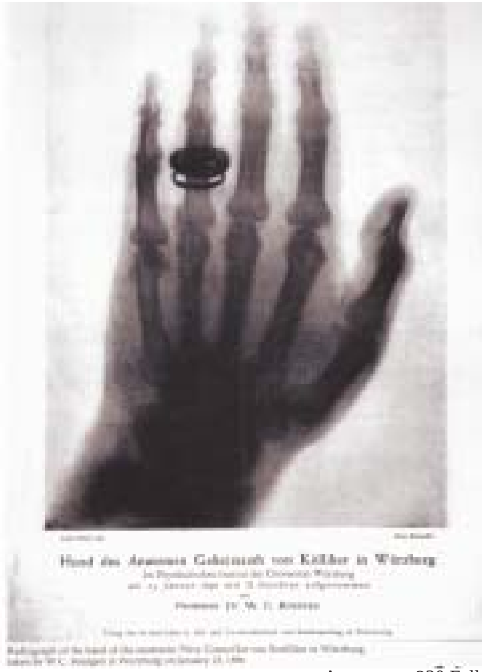
Charles Darwin



Charles Lyell



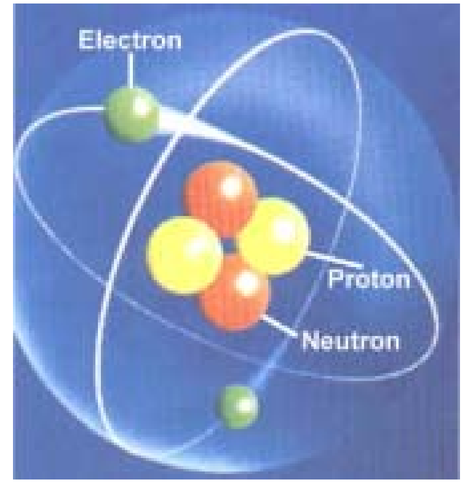
William Thomson, Lord Kelvin



Eyes began to turn to the nuclear processes of the Atoms

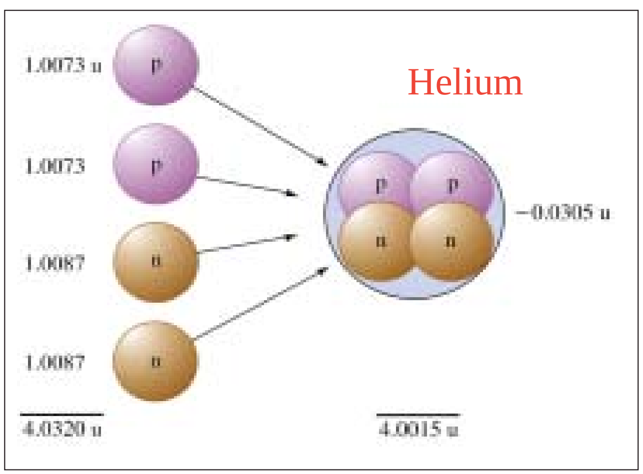
Back to Atoms

Remember that the atom consists of a nucleus and electrons moving around the nucleus.



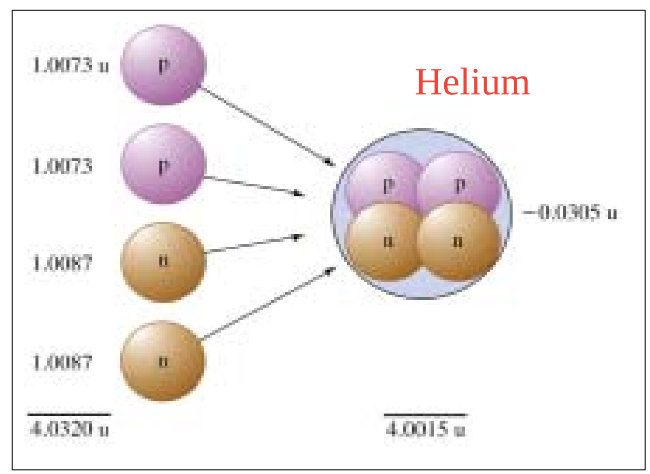
The Nucleus

- Okay, so we know that the nucleus can have numerous protons (+'s) very close.
- **Something is odd here!**
- **What is it?**



The Nucleus

- **Why doesn't the nucleus of the atom fly apart?**



4 Fundamental Forces

- Gravity
- Electromagnetic
- Strong Nuclear
- Weak Nuclear

Gravity

- As described by Newton
- The weakest of the forces, yet it is the dominant force in the Universe for shaping the large scale structure of galaxies, stars, etc.
- Only purely attractive force
- Arguably the least understood force
- Infinite range

Electromagnetic

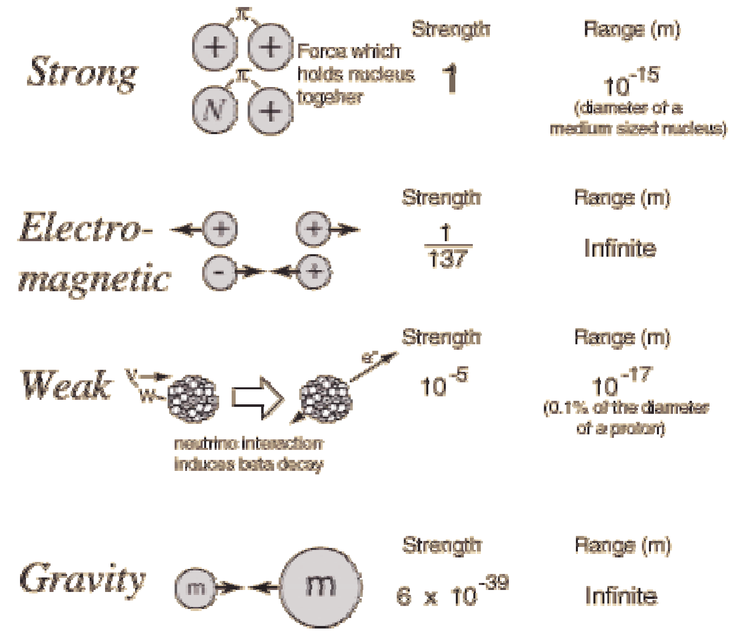
- Similar to the gravitation force (inverse square law)
- Electric and Magnetic fields
- Both attractive and repulsive force
- Only acts on charges particles
- Responsible for all electric and magnetic phenomena we observe— includes light.
- Infinite range

Strong Nuclear

- The strongest of the 4 forces
- The force which holds an atom’s nucleus together, in spite of the repulsion between the protons.
- Does not depend on charge
- Not an inverse square law– <u>very short range</u>.

Weak Nuclear

- Moderates certain kinds of nuclear decays such as the neutron decay
- The most common particle which interacts only via the Weak Force is the *neutrino*
- Very short range



Nuclear Fusion in the First Stars

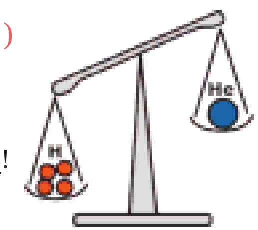
- Core T > 10 million K
  - violent collisions
  - e^- stripped from atoms (ionized)
  - nuclei collide, react
- Thru series (chain) of reactions
- 4 protons ⇒ helium (2p,2n) nucleus + energy
- **Fusion:** light nuclei combine ⇒ heavier nuclei

Why does fusion release energy?

Fusion: $4\,p \rightarrow {}^4\mathrm{He} \quad (2\,p, 2\,n)$

Fact: **4m(*p*) > m(^{4}He)** !

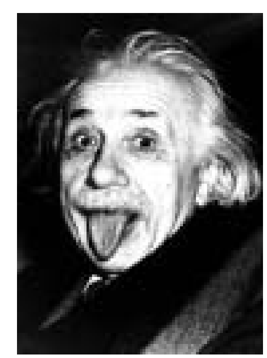
mass of whole < mass of parts!



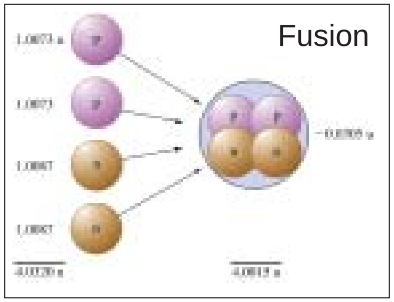
Einstein says ***E* = *mc*^{2}**:

- Mass is a form of energy!
- Each ^{4}He liberates energy:

$$E_{\mathrm{fusion}} = m_{\mathrm{lost}} c^2 = 4m(p)c^2 - m({}^4\mathrm{He})c^2 > 0!$$



Nuclear Reactions



- Atomic nuclei can combine or split
- Release energy in process ($E = mc^2$)
- Light nuclei: fusion
- Heavy nuclei: fission