Astronomy 330

This class (Lecture 6):

Stars

Next Class:

Star Formation

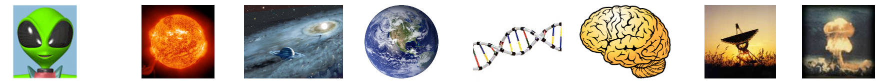
Synopsis Due on Sunday!

Music: *We are all made of Stars* – Moby

Drake Equation

The class's first estimate is

Frank Drake



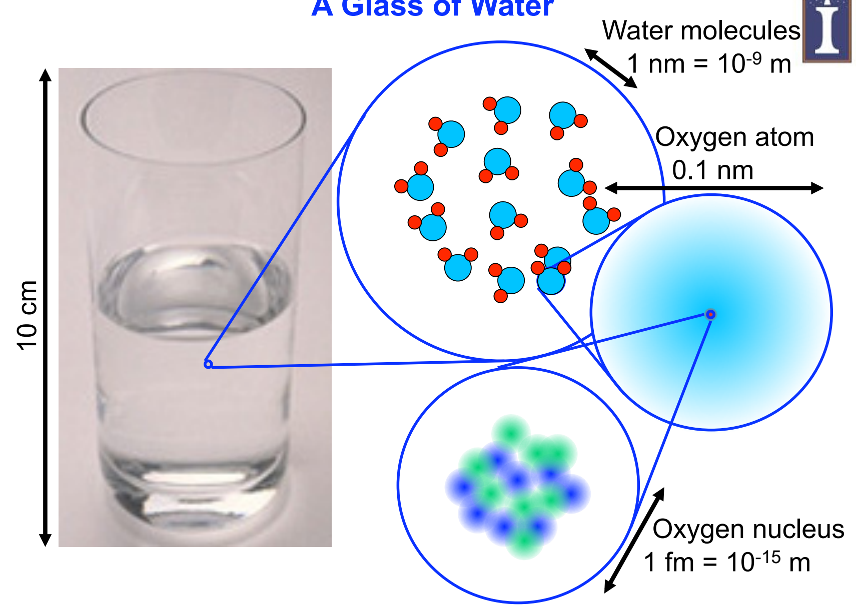
$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	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
	20 stars/ yr	systems/ star	planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

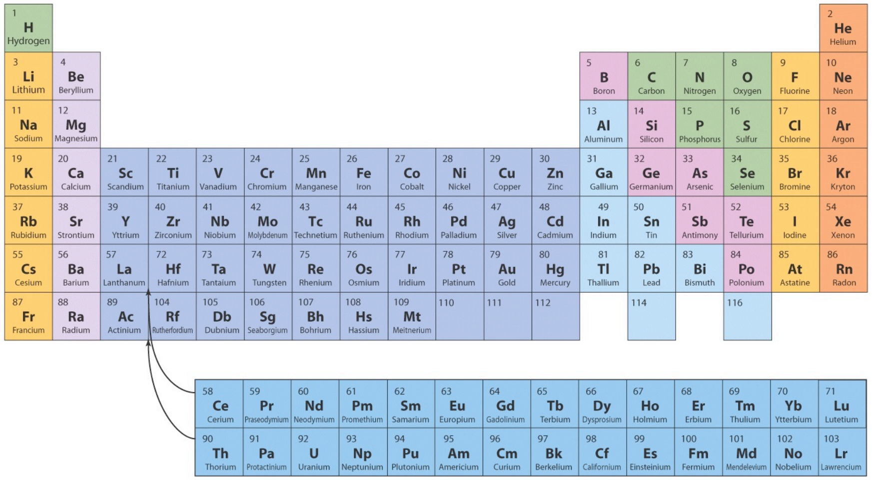
Outline

- The first stars
- How does the Sun shine?
- Supernovae

A Glass of Water



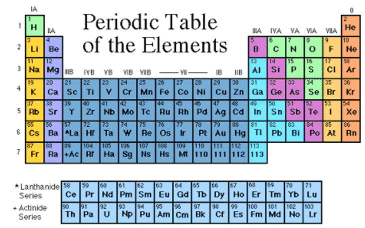
The Periodic Table of the Elements



The number of protons in an atom determines the type of element, and the number of protons and neutrons determine the atomic weight.

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

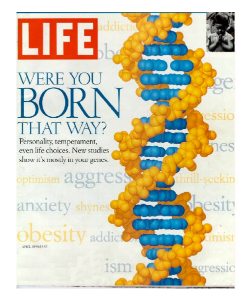
By Number…

- 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

Little Pink 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.



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

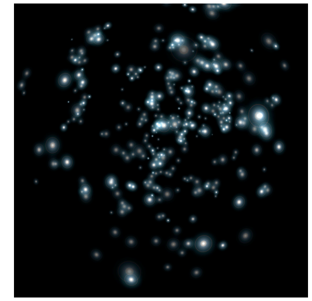
Question

What can say about the elemental make-up of life on Earth, the Earth, and the Universe?

a) All three are made up of the same elements in the same amounts.
b) The Universe is mostly hydrogen, but the Earth and life on Earth are mostly oxygen.
c) The Earth and the Universe are mostly hydrogen.
d) Life on Earth and the Universe are mostly carbon.
e) They are made up of the same elements but different concentrations.

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 proto-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?



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

Water Power?

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

The water has potential energy. It wants to flow downhill. If I pour it out, the conservation of energy tell us that it must turn that potential energy into kinetic energy (velocity). The water wants to reach the center of the Earth. This is how we get hydro energy from dams.

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 (or snowballing), 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.

http://www.rob-clarkson.com/duff-brewery/snowball/04.jpg

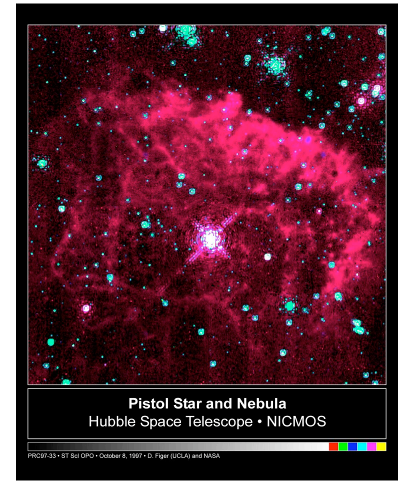
Cooking with Gas

- For the first time, since 1-month after the Big Bang, the centers of the clumps get above 10^7 K.
- Now 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.

http://lgeku.energyunderground.com/images/images-deepearth/BURNERBL.jpg

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?

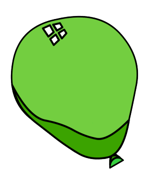


http://www.u.arizona.edu/~justin/images/hubblepics/full/PistolStarandNebula.jpg

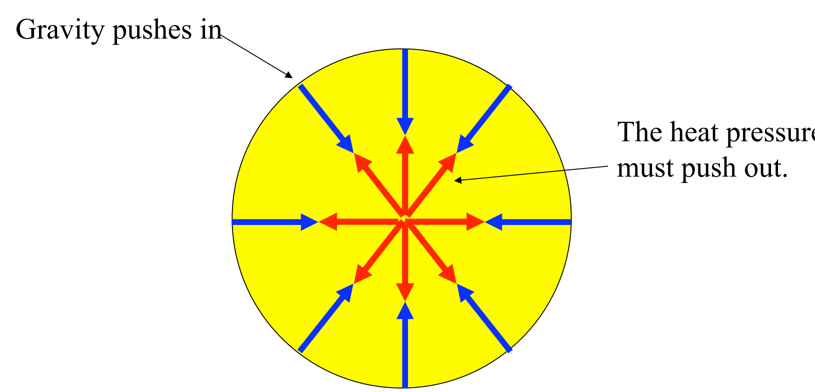
Pressure

- 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



Hydrostatic equilibrium: Balanced forces

The Sun’s Energy Output

3.85×10^{26} Watts, but how much is that?

A 100W light bulb…

…the Sun could supply 4×10^{24} light bulbs!

U.S. electricity production in 2006: 4.1 trillion kWh…

… Sun = 3×10^{7} times this *every second*

World’s nuclear weapons: 3×10^{4} megatons…

… Sun = 4 million times this *every second*

Question

A star is in hydrostatic equilibrium. What does that mean?

a) Pressure from fusion is pushing back against the force from planetary orbits.

b) The star’s radius does not change much.

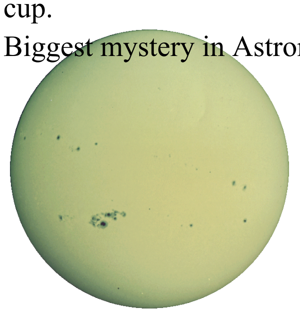
c) Pressure from fusion is winning the war against gravity.

d) Gravity is perfectly balanced with electromagnetism.

e) None of the above.

So, What Powers the Sun?

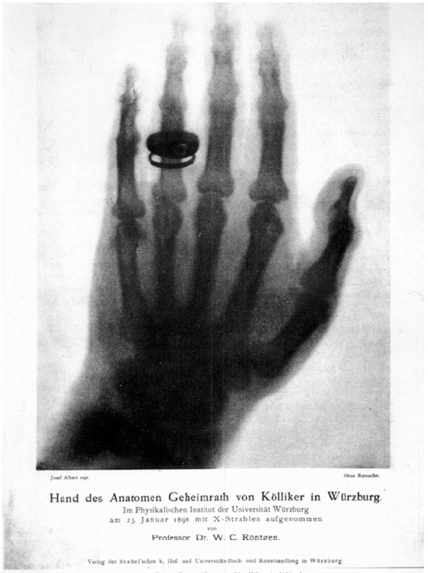
- The Sun does not collapse nor even change it’s radius.
- Gravity pushes in, but what pushes out?
- What is its power source?
- What keeps the Sun hot? It doesn’t cool like a hot coffee cup.
- Biggest mystery in Astronomy up until 20th century.



How to Test?

- Without an energy source, the Sun would rapidly cool & contract
  - Darwin: evolution needs Sun & Earth to be > 10^{8} years old
  - Lyell: geological changes also needs > 10^{8} years
- Process must be able to power Sun for a long time! At least 4.5 Byrs.

- Gravity:
  - Seems like a good idea. Remember Jupiter gives off heat.
  - A contracting Sun releases gravitational energy.
  - But only enough for 20 million years
- Chemical:
  - If the Sun was made from TNT, something that burns very well, then it would last for 20,000 years



Radiograph of the hand of the anatomist Privy Councillor von Koelliker in Würzburg, taken by W. C. Röntgen in Würzburg on January 23, 1896

Eyes began to turn to the nuclear processes of the Atoms

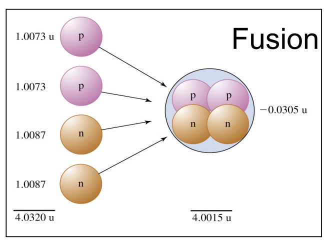
What is Fusion?

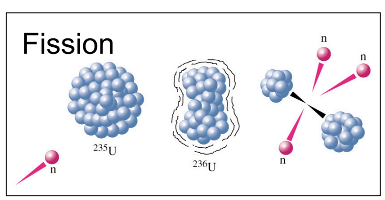
$$4p \longrightarrow {}^{4}\mathrm{He}\,(2p,2n)$$

Basic idea is to take 4 protons (ionized hydrogen atoms) and slam them together to make an ionized helium atom.

Fusion vs. Fission

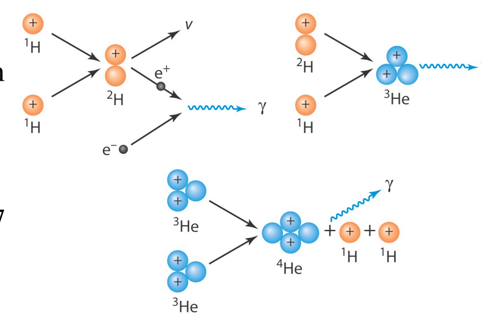
- Light nuclei: fusion
  - Happens in the Sun
  - H-Bomb
- Heavy nuclei: fission
  - Used in power plants
  - A-Bomb





Nuclear Fusion in the Sun's Interior

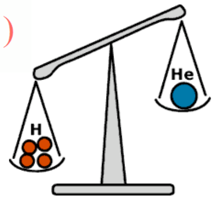
- Proton-Proton Chain
  - 4 Hydrogen atoms fuse to make 1 helium atom
  - Requires very high density and temperature (at least 7 million K)



The Proton-Proton (p-p) Chain

Why does fusion release energy?

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

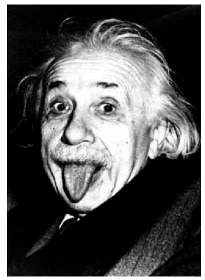


Fact: **$4m(p) > m(^4\mathrm{He})$** !
<u>mass of whole < mass of parts</u>!

Einstein says ***$E = mc^2$***:

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

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

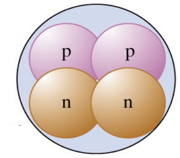


The Nucleus

- Okay, so we know that the nucleus can have numerous protons (+'s) very close.

Helium

- **Something is odd here!**
- **What is it?**

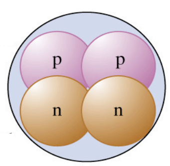


The Nucleus

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

Helium

- **Something is odd here!**
- **What is it?**



4 Fundamental Forces

- Gravity
- Electromagnetic
- **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

Question

What powers the Sun?

a) Nuclear burning.
b) Nuclear burning of helium to carbon.
c) Nuclear burning of dreams to pure energy.
d) Nuclear burning of hydrogen to helium.
e) Nuclear burning of carbon to helium.

Nuclear Reactions in the Sun

- Chain: 4 protons ⇨ helium
- First step in chain (2 protons combine):

$$p + p \rightarrow [np] + e^{+} + \nu$$

- Start with 2 particles (protons)
- End up with 4 particles (two of which are glued together)
- each of products is very interesting in its own right....

Nuclear Reactions in the Sun

$$p + p \rightarrow [np] + e^{+} + \nu$$

$[np]$ = **deuterium**

- 1 proton + 1 neutron bound together into nucleus of element…
- Hydrogen, but has neutron, so 2 times mass of normal H
  - "Heavy Hydrogen"
- Simplest composite nucleus

Discovery of D in lab: *Nobel Prize*
about 0.01% of all H on earth is D
✓ including in your body:
you contain about 10 kilos (20 lbs) of H, and about 2 grams of D
✓ Water (normally H_2O) with D is D_2O : "heavy water"

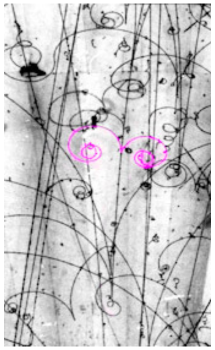
Nuclear Reactions in the Sun

$$p + p \rightarrow [np] + e^{+} + \nu$$

e^{+} = **positron**

- Exactly the same as electron but charge **+1**
- **Antimatter**
- Combines with normal e^{-}
  - Both are gone, release of energy
  - ***Annihilation***

Discovery of positron in lab: *Nobel Prize*
Because of this reaction
➢ The Sun contains a small amount of antimatter!



Nuclear Reactions in the Sun

$$p + p \rightarrow [np] + e^{+} + \nu$$

ν (Greek letter "nu") = **neutrino**

- Particle produced in nuclear reactions ***only***
- Tiny mass: $m(\nu) < 10^{-6} m(e)$!
- Moves at nearly the speed of light
- ***Very*** weakly interacting

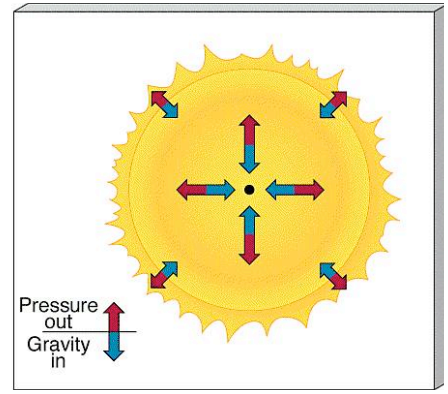
Discovery of neutrino in lab: *Nobel Prize*

10 billion from Sun go through hand every sec

- ➢ Reach out!
- ➢ Go through your body, Earth, but almost never interact

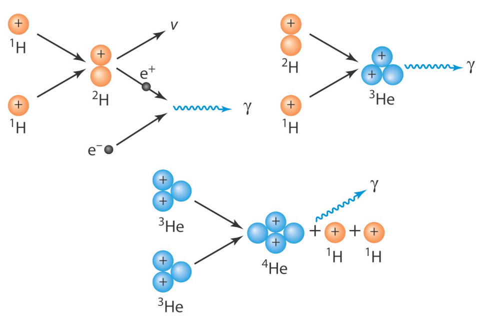
Why Doesn't The Sun Shrink?

- Sun is currently stable
- Pressure from the radiation created by fusion balances the force of gravity.
- There has to be some pressure. The pressure is from fusion!



Nuclear Fusion in the Sun's Interior

- Proton-proton in stars like the Sun
  - Hydrogen fused to make helium
  - 0.7% of mass converted to energy



The Proton-Proton Cycle

They Might Be Giants
Why Does The Sun Shine

Why Does the Sun Shine?

The Sun is a mass of incandescent gas
A gigantic nuclear furnace
Where hydrogen is built into helium
At a temperature of millions of degrees

The Sun is hot, the sun is not
A place where we could live
But here on Earth there'd be no life
Without the light it gives

We need its light
We need its heat
The Sun light that we seek
The Sun light comes from our own sun's atomic energy

The Sun is a mass of incandescent gas
A gigantic nuclear furnace
Where hydrogen is built into helium
At a temperature of millions of degrees

The Sun is hot

The Sun is so hot that everything on it is a gas: Aluminum, Copper, Iron, and many others

The Sun is large... If the sun were hollow, a million Earth's would fit inside
And yet, it is only a middle-sized star

The Sun is far away... About 93,000,000 miles away
And that's why it looks so small

But even when it's out of sight
The Sun shines night and day
We need its heat, we need its light
The Sun light that we seek
The Sun light comes from our own sun's atomic energy

Scientists have found that the Sun is a huge atom smashing machine
The heat and light of the sun are caused by nuclear reactions between Hydrogen, Nitrogen, Carbon, and Helium

The Sun is a mass of incandescent gas
A gigantic nuclear furnace
Where Hydrogen is built into Helium
At a temperature of millions of degrees