Astronomy 330

<u>This class (Lecture 6):</u>

Molecular Clouds

<u>Next Class:</u>

Why does the Sun shine?

Synopsis due tonight

Music: *Carl Sagan -Glorious Dawn*– Colorpulse
http://www.youtube.com/watch?v=zSgiXGELjbc&feature=fvw

Outline

- The End of the Universe
- Molecular Clouds
- Why does the Sun shine?

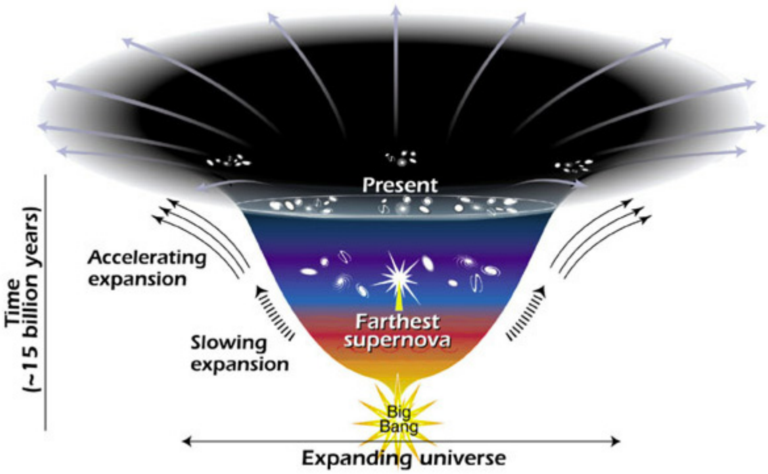
Last Year's Best

- **Top Presentation**
  Europa Rocks!

Dark Energy

- We spent the last class discussing Dark Energy.
- In groups write a 4-5 sentence explanation of Dark Energy to a non-science major friend.
  - What are the essential points?

Effects of Dark Energy



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

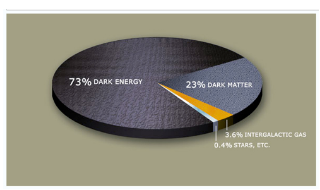
Question

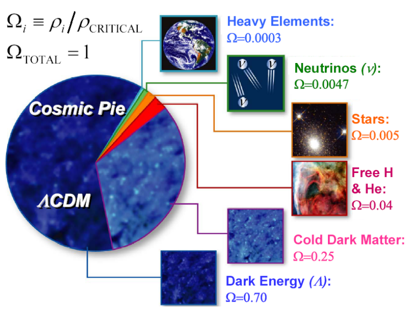
Based on measurement of the CMB, we live in a flat Universe. But there is not enough known mass to account for this. What's up?

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.

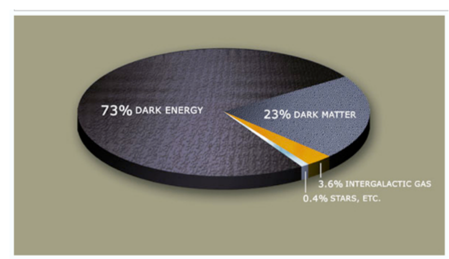




Dark Energy even dwarfs dark matter! Regular matter is really insignificant. We *really* don't know anything about what's going on!!

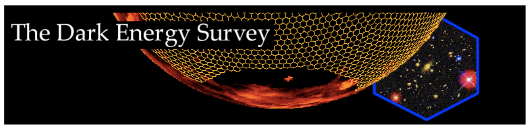
The Accelerating Universe!!!

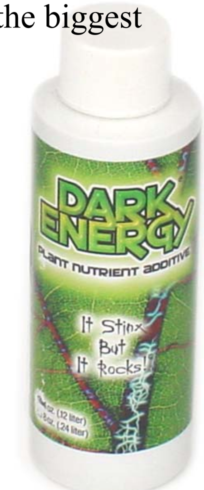
- But, we are still in very speculative times here.
- How the Universe ends will depend on the nature of Dark Energy.
- If it really acts like a cosmological constant (go Einstein!), then we live in a flat Universe that will keep expanding forever, but if not then we don't know yet.



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?





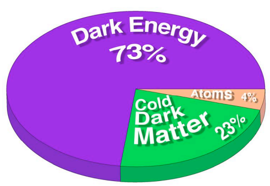
The Distant Future: The Big Rip

- 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

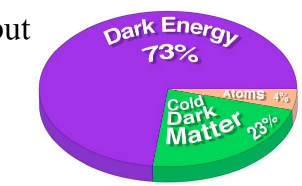
The Distant Future: The Big Crunch

- 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?

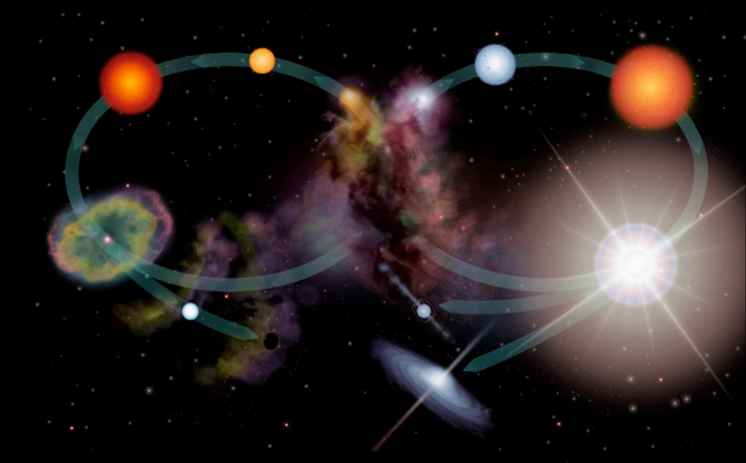
What are Galaxies?

- 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.

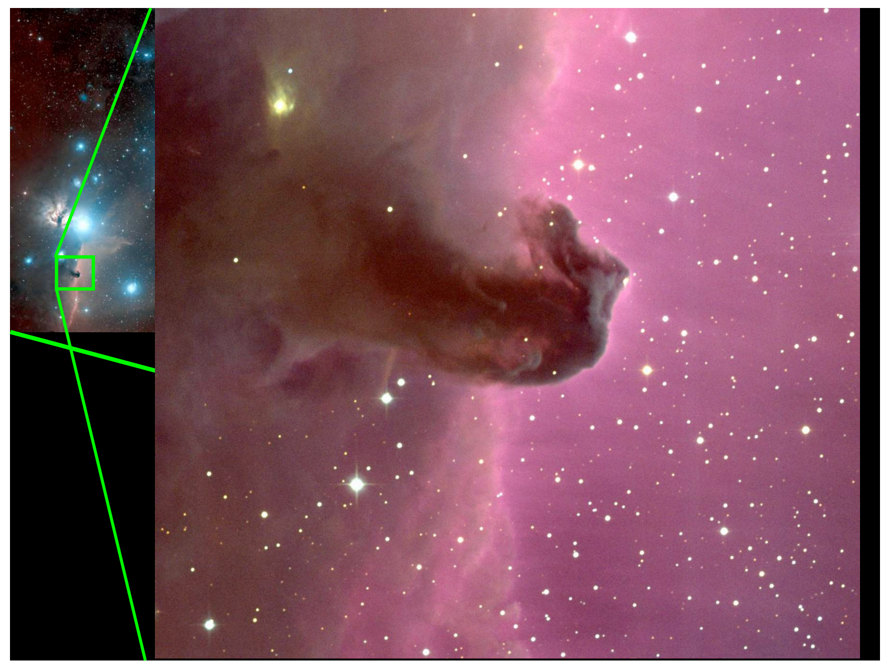
Stellar Evolution Re-Cycle



The Interstellar Medium (ISM)

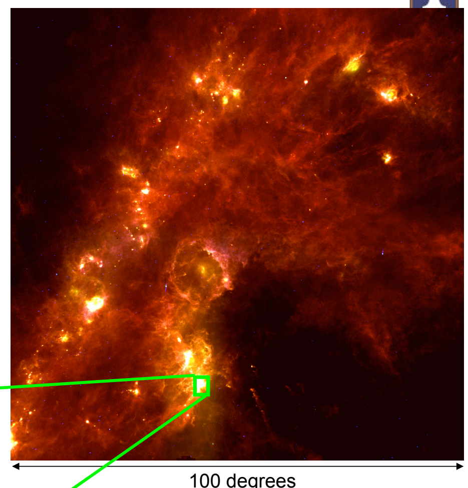
- Stuff between the stars in a galaxy.
- Sounds sort of boring, but
  - Actually very important
  - Features complex physical processes hidden in safe dust clouds
- Every star and planet, and maybe the molecules that led to life, were formed in the dust and gas of clouds.
- Exists as either
  - Diffuse 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

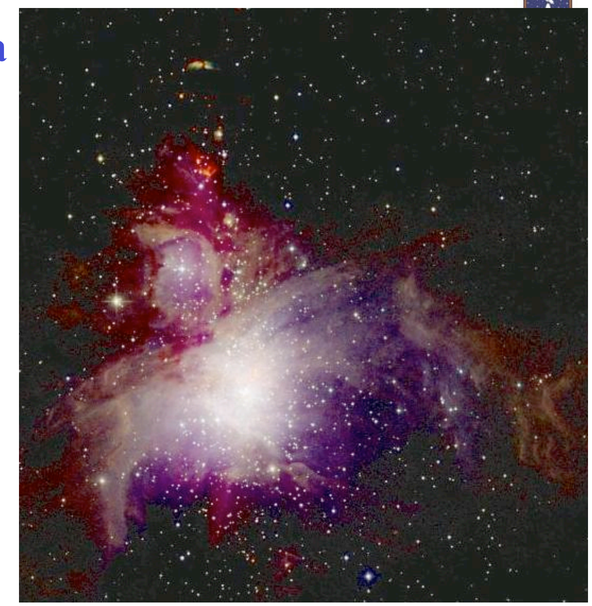


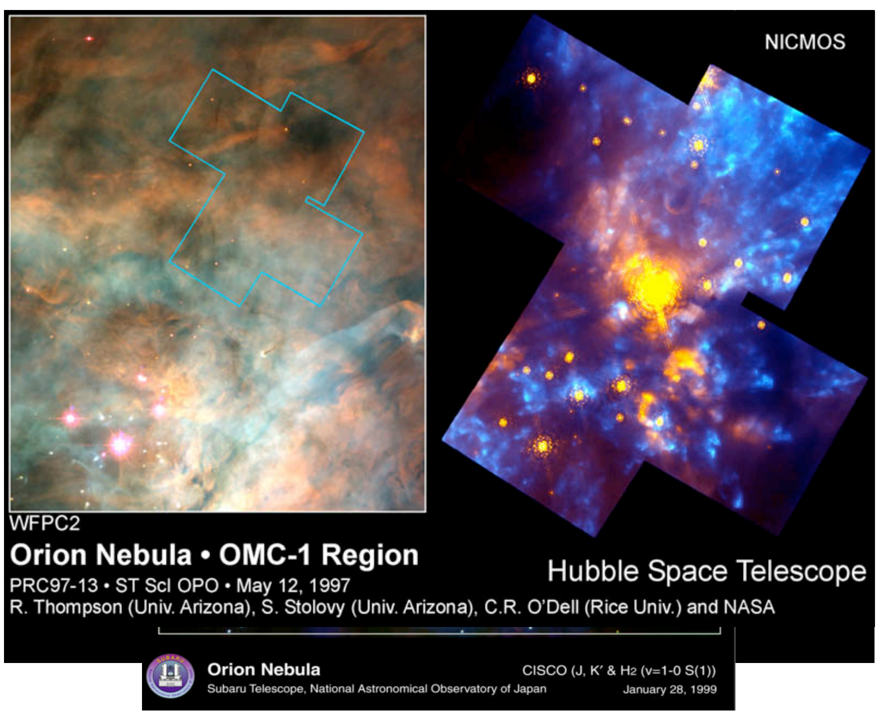
Infrared image from *IRAS*

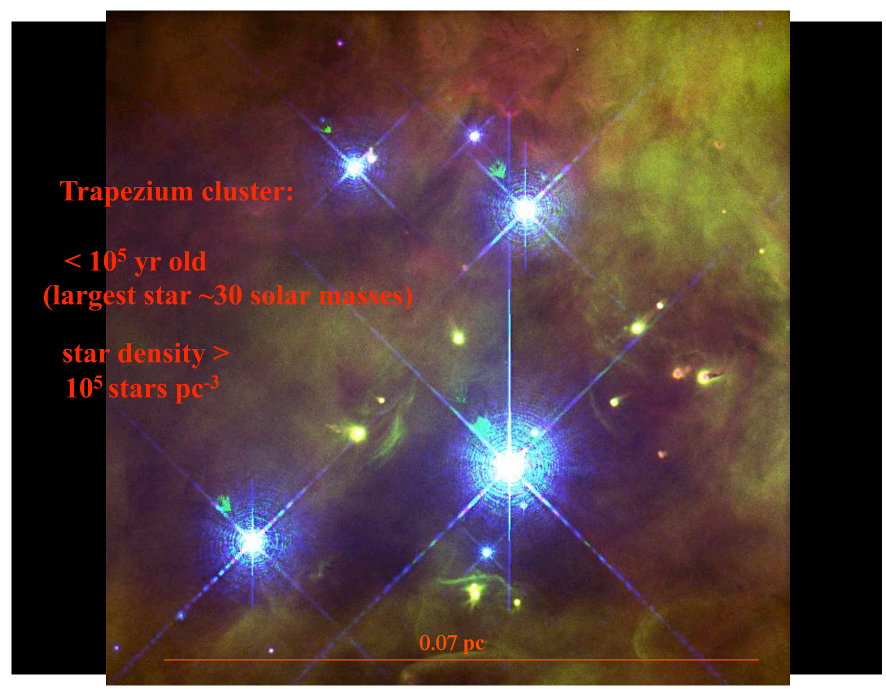
Orion Nebula

(near infrared)

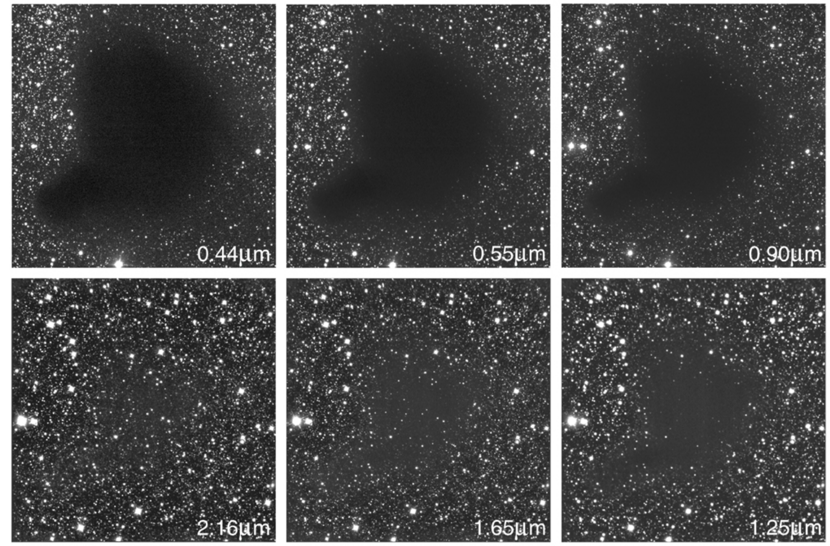
Nearest massive star forming region with a large molecular cloud associated (distance of 1500 lys)







Interstellar Clouds



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

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

Drake Equation

Frank Drake

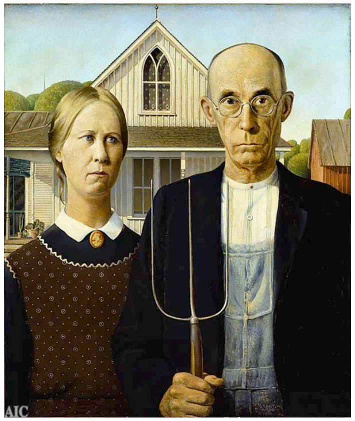
$$N = R_{*} \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

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

Lifecycle of a Star

- Star formation
  - Take a giant molecular cloud core with its associated gravity and wait for 10^4 to 10^7 years.
- Star Death
  - Exhaust hydrogen
  - Red giant / supergiant or supernova
  - White dwarfs, neutron stars, black holes

Stellar Lifestyles



Low-mass stars

many of these

Massive stars

few of these

Lifecycle of a Star

- Star formation
  - Take a giant molecular cloud core with its associated gravity and wait for 10^4 to 10^7 years.

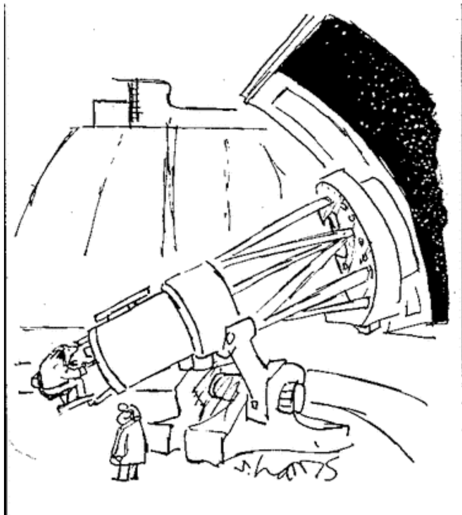
- Star Death
  - Exhaust hydrogen
  - Red giant / supergiant or supernova
  - White dwarfs, neutron stars, black holes
- Main sequence life (depends on mass!)
  - Few x 10^6 years to more than age of Universe
  - Thermonuclear burning of H to He

Stars

- The fundamental building blocks of the Universe.
- High mass stars are 8 to 100 solar masses
  - Short lived: 10^6 to 10^7 years
  - Luminous: 10^3 to 10^6 L_{sun}
  - Power the interstellar medium– input of energy
- Intermediate mass stars are 2 to 8 solar masses
- Low mass stars are 0.4 to 2 solar masses
  - Long Lived: $>10^9$ years
  - Good for planets, good for life.
  - Not so luminous: 0.001 to 10 L_{sun}

Estimate of R_*: The Star Formation Rate

- We are about to start the topic of star formation and planet formation, but really the field is not well enough developed to estimate R_*.
- It is more accurate to just take the total number of stars in the Galaxy and divide by the age of the Galaxy.
- Later we will correct for the stars that are too big, too small, or too variable.


"Let's see, now ... picking up where we left off ... one billion, sixty-two million, thirty thousand, four hundred and thirteen ... one billion, sixty-two million, thirty thousand, four hundred and fourteen ... "

Counting Stars

Estimate of R_*:
The Rate of star formation

Take the total number of stars in the galaxy and divide by how long it took those stars to form.

Sounds easy, but it isn't. We can't see all of the stars, interstellar dust blocks our view of most of them.

We can estimate the number of stars based on the total mass of the Galaxy and some corrections.

$$N_* = 5\times10^{10} \text{ to } 5\times10^{11} \text{stars}$$

Estimate of R_*:
The Rate of star formation

Age of our galaxy is around 10^{10} years (if you want to be more precise, use 13.7 billion years minus ~200 million).

$$R_* = \frac{5\times10^{10} \; to \; 5\times10^{11} \, stars}{10^{10} \, years} = 5 \; to \; 50 \frac{stars}{year}$$

(Keep in mind that these are stars of all masses)
Still, probably the best estimate for the entire Drake Equation, meaning it can only be off by a factor of 10 or so. Solid.

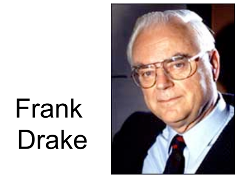
Estimate of R_*:
Discuss

$$R_* = \frac{5\times10^{10} \text{ to } 5\times10^{11} \, stars}{10^{10} \, years} \approx 5 \text{ to } 50 \frac{stars}{year}$$

1. Discuss the calculation of this value.
2. Choose a lower/higher number if you think that the star formation rate was biased by non-uniform star formation.
   - Did the early galaxy produce more stars in the past than it does now? Was there a starburst long ago?
   - But remember that we are constantly obtaining new gas from our satellite galaxies (around 1 solar mass per year). It might average out.

Drake Equation

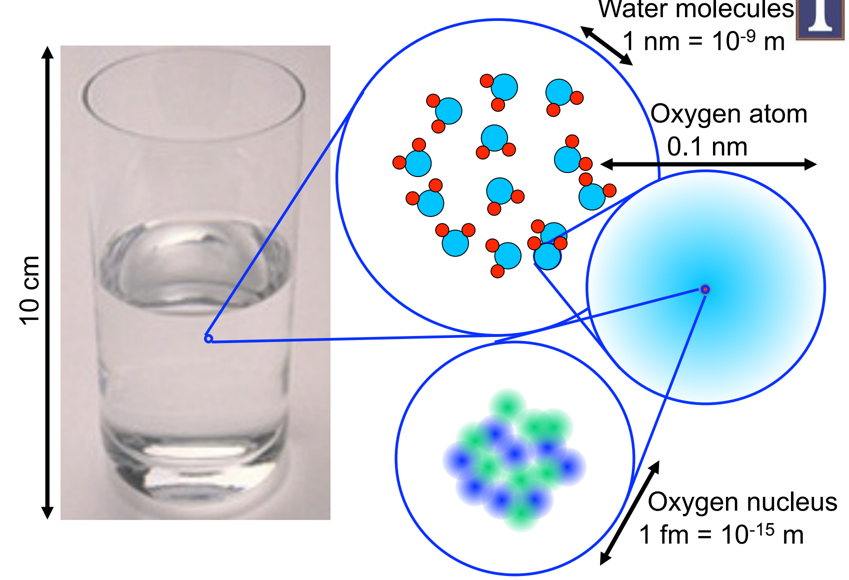
The class's first estimate is



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

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
	15 stars/yr	systems/star	planets/system	life/planet	intel./life	comm./intel.	yrs/comm.

A Glass of Water



The Periodic Table of the Elements

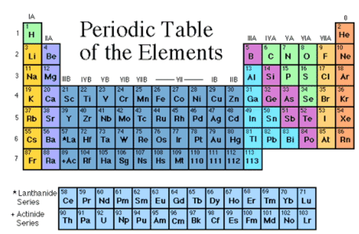
1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	57 La Lanthanum	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89 Ac Actinium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110	111	112		114		116		

58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

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

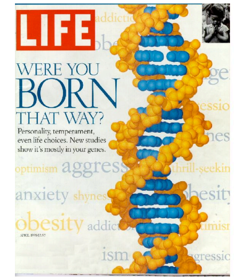
By Number…

- 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.
- The Universe does this through star formation.



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

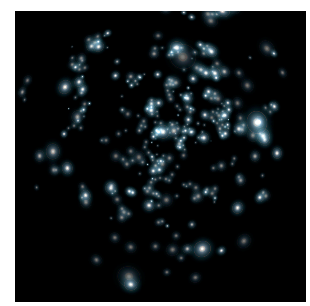
Question

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.
- First Stars 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

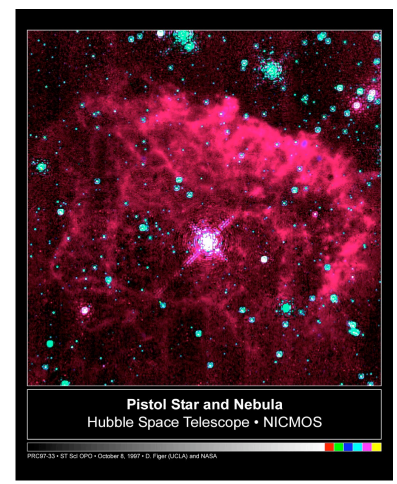
Cooking with Gas

- 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

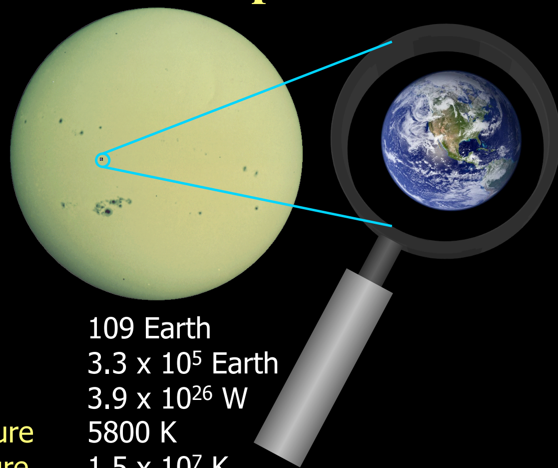
- The Pistol star near the Galactic center started as massive as 200 solar masses.
- Releases as much energy in 6 seconds as the Sun in a year.
- But it blows off a significant fraction of its outer layers.
- How did the first stars stay so massive?
- Perhaps they are slightly different than this case?



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

Earth-Sun Comparison

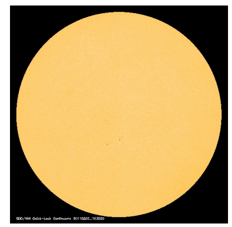
In general, a very typical star. Keep in mind that it is really a ball of gas/ plasma.

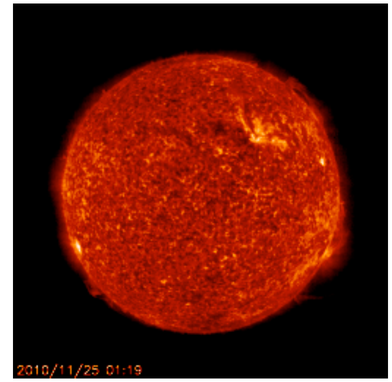


Visual radius	109 Earth
Mass	3.3×10^5 Earth
Luminosity	3.9×10^{26} W
Surface temperature	5800 K
Central temperature	1.5×10^7 K
Rotation period	25 days

LIVE from the Sun

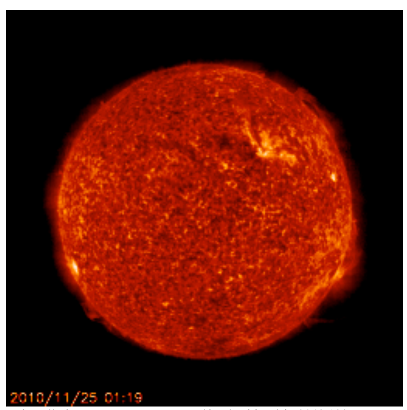
http://sohowww.nascom.nasa.gov/data/realtime/mpeg/





Question of Stability

- The Sun's size is constant.
- No weatherman says it will be especially hot tomorrow as the Sun's size will be increasing.
- Not expanding or collapsing.
- The Sun is stable! Why?

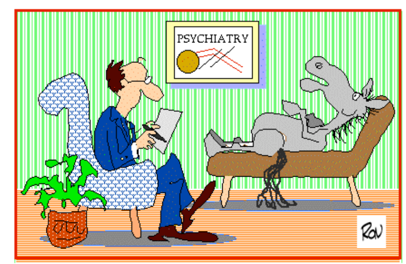


http://sohowww.nascom.nasa.gov/data/realtime/eit_304/512/

http://www.londonstimes.us/toons/index_medical.html

Question of Stability

- Not trivial, could have gone the other way
- Think: Sun is made of gas, yet not like a cloud, for example, which is made of gas but size, shape changes all of the time
- Not a coincidence: really good reason



"I just don't feel stable."

http://www.londonstimes.us/toons/index_medical.html

Why is the Sun Stable?

- What keeps gravity from collapsing the Sun?

- What keeps the Sun from exploding?