Astronomy 330

<u>This class (Lecture 5):</u>

Star Formation

<u>Next Class:</u>

Why does the Sun Shine?

Presentation Synopsis due tonight!

Music: *Across The Universe* – The Beatles

Outline

- Star Formation.. today….
- Why does the Sun shine?

Dark Energy

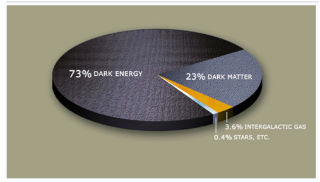
- We spent the last class discussing Dark Energy.
- In groups write a 4-5 sentence explanation of Dark Energy to a non-science major friend.
  - What is the fate of the Universe?

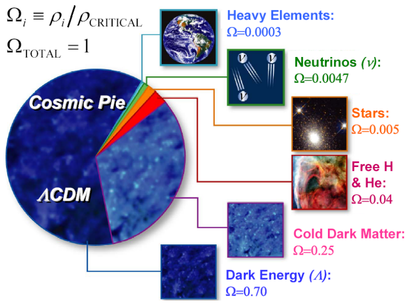
The Universe

- Began with a Big Bang
  - <u>13.7 billion years ago</u>
- 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 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!!

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?

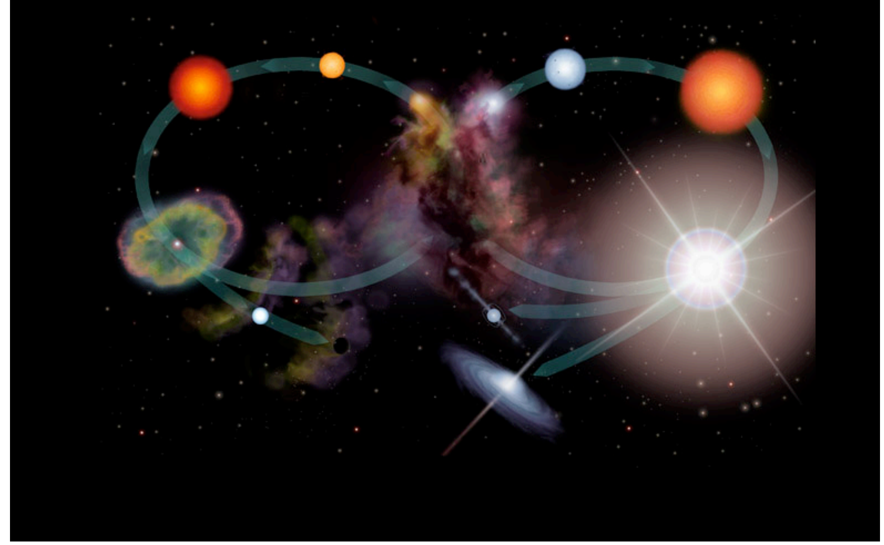
What are Galaxies?

- 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)

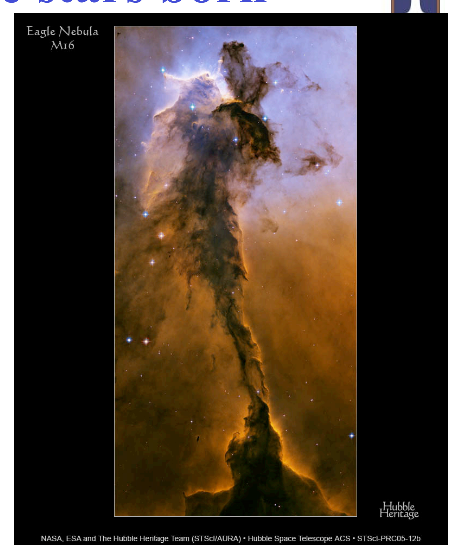
- Stuff between the stars in a galaxy.
- Sounds sort of boring, but
  - Actually very important
  - Features complex physical processes hidden in safe dust clouds

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

Keyhole Nebula

Where are stars born

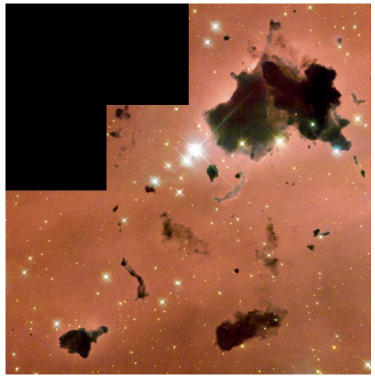
- To find where stars are born, we look at young stars
  - Often occur in clusters
  - Generally found near their birthplaces
- Young stars are found near nebulae
  - Clouds of gas and dust in space



A portion of the Eagle Nebula

Stars are born in cold clouds of gas & dust

- Stars are born in giant, dusty gas clouds called molecular clouds
  - Most of the matter in star-forming clouds is in the form of molecules (H_2, CO,…)
  - Also contain icy dust
- These clouds are cold!
- Temperatures of just 10-30 K! (-405 F!)

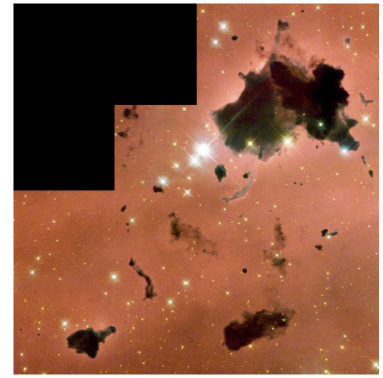


NASA and The Hubble Heritage Team (STScI/AURA)

Stars form within dark, cold dusty clouds in space seen here in absorption against a bright background.

Stars are born in molecular clouds

- The clouds have densities of 10^2 to 10^5 molecules per cubic cm.
- Huge: 10-300 light years across.
- Massive: 10^5 to 10^6 solar masses
- You might be wondering how the unimaginably cold gas of an interstellar cloud can heat up to form a star. The answer is gravity.



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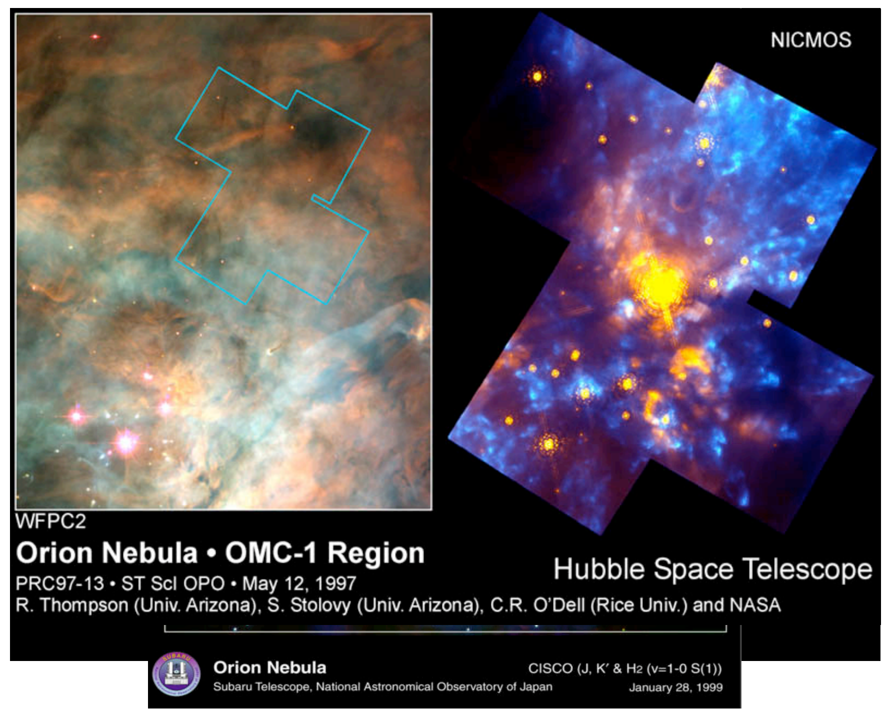
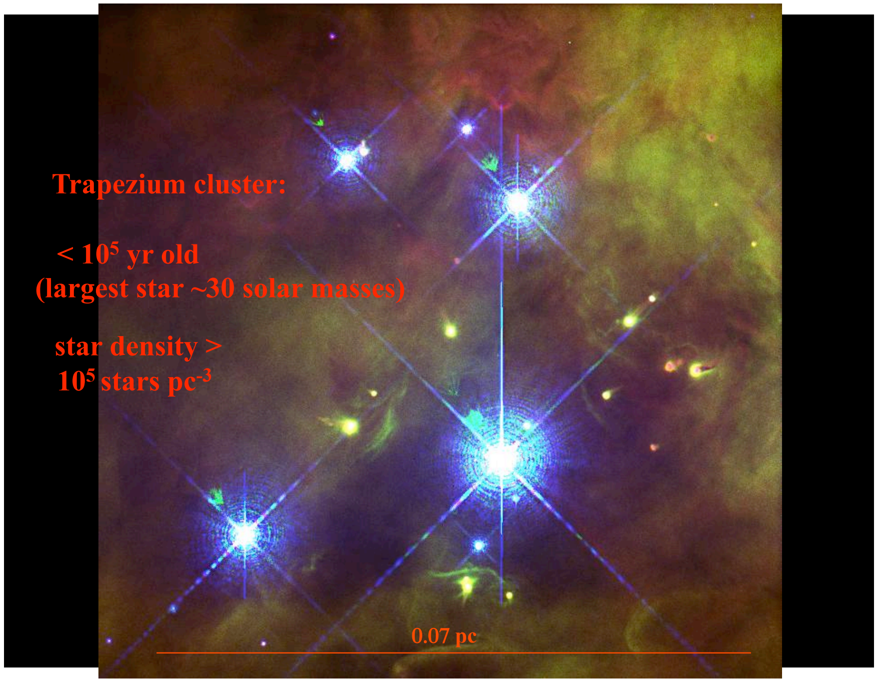
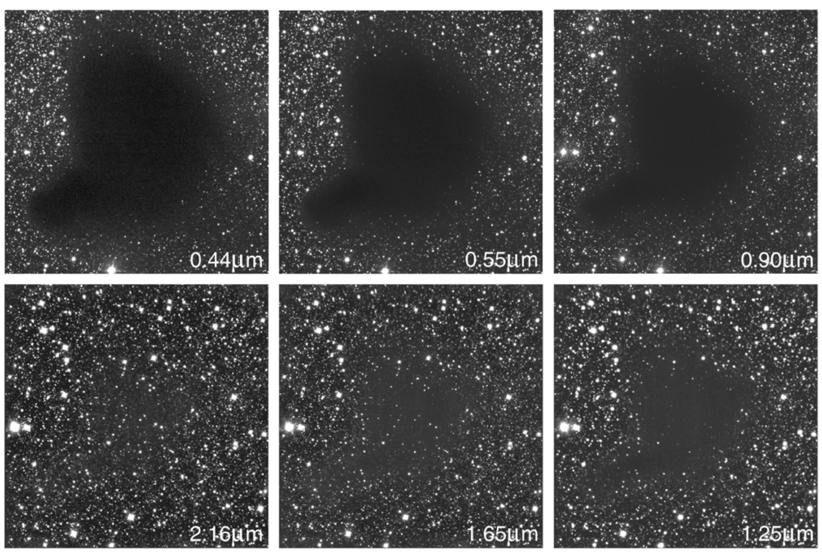




Interstellar Clouds



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

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

Drake Equation

Frank Drake

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

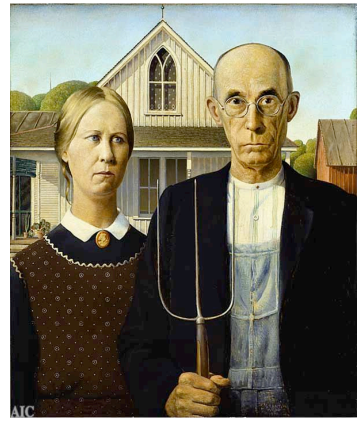
N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	? 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
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- Main sequence life (depends on mass!)
  - Few x 10^6 years to more than age of Universe
  - Thermonuclear burning of H to He

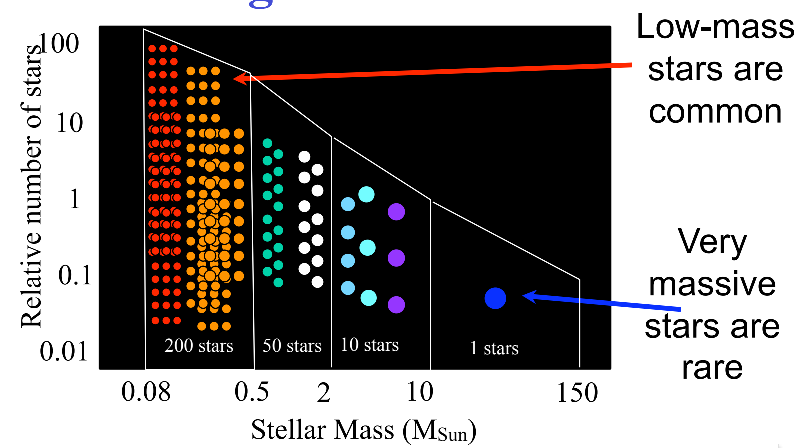
Stars

- 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}

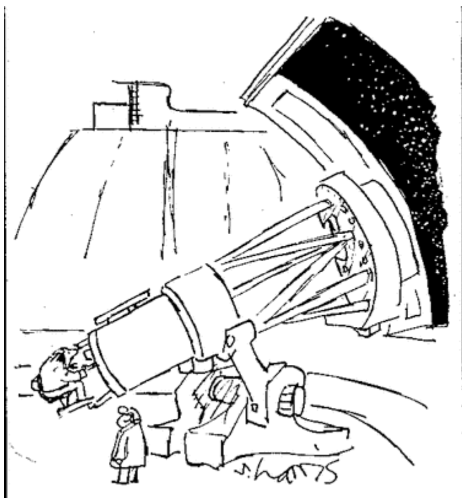
Estimate of R_*:
The Star Formation Rate

- Galaxy evolution, star formation, triggered star formation, etc. fields are not well enough developed to estimate R_*.
- It is more accurate to just take the total number of stars in the Galaxy today and divide by the age of the Galaxy.
- Later we will correct for the stars that are too big, too small, or too variable.

More low mass stars form than high mass stars



Stars more massive than 150 M_{Sun} would blow apart. Stars less massive than 0.08 M_{Sun} can't sustain fusion.



"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.

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

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

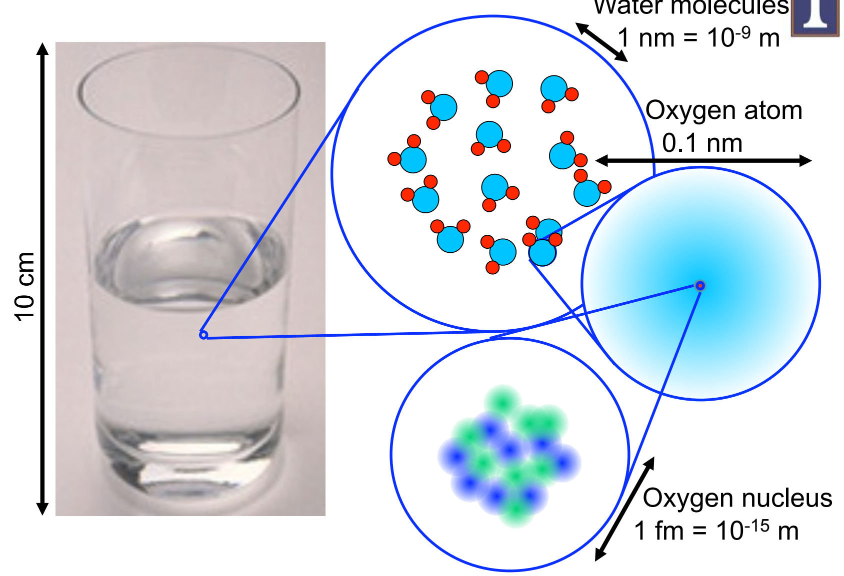
The class's first estimate is

Frank Drake

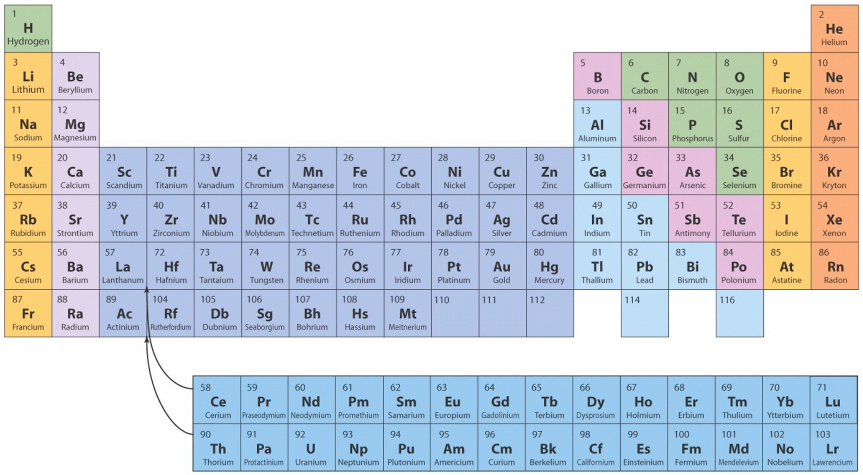
$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

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.

A Glass of Water



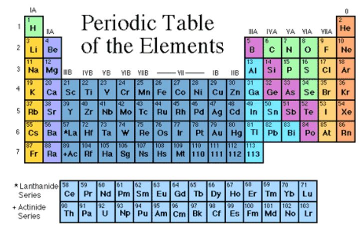
The Periodic Table of the Elements



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:
  - 6×10^{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

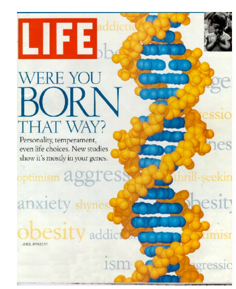
By Number…

- 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

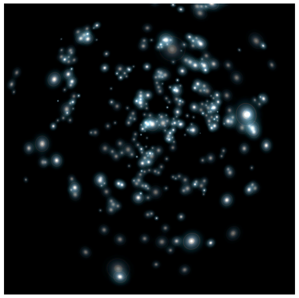
Question

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

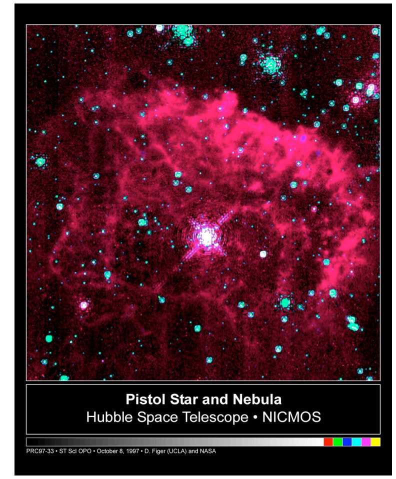
Cooking with Gas

- 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 today? 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

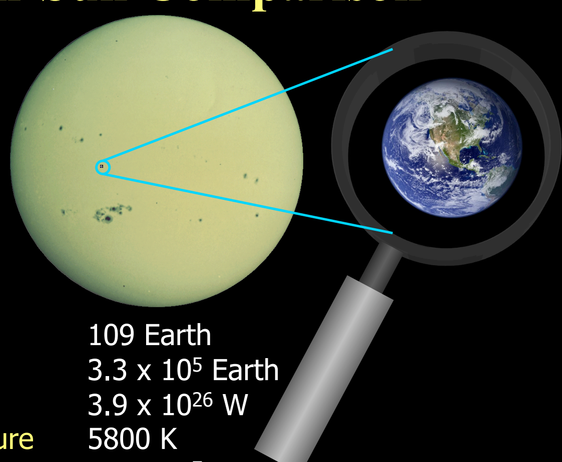
- The Pistol star near the Galactic center started as massive as 200 solar masses.
- Releases as much energy in 6 seconds as the Sun in a year.
- But it blows off a significant fraction of its outer layers.
- How did the first stars stay so massive?
- Perhaps they are slightly different than this case?



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

Earth-Sun Comparison

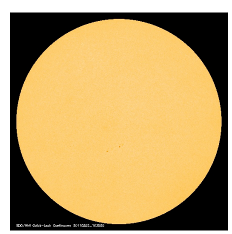
In general, a very typical star. Keep in mind that it is really a ball of gas/plasma.

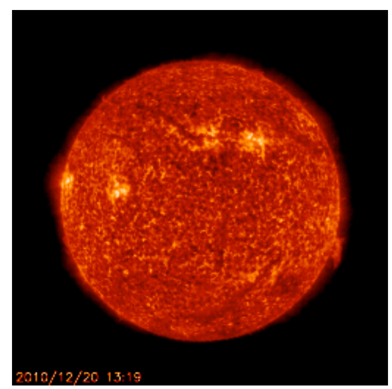


Visual radius	109 Earth
Mass	3.3×10^5 Earth
Luminosity	3.9×10^{26} W
Surface temperature	5800 K
Central temperature	1.5×10^7 K
Rotation period	25 days

LIVE from the Sun

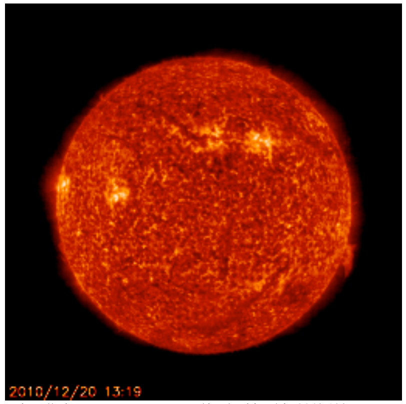
http://sohowww.nascom.nasa.gov/data/realtime/mpeg/





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?

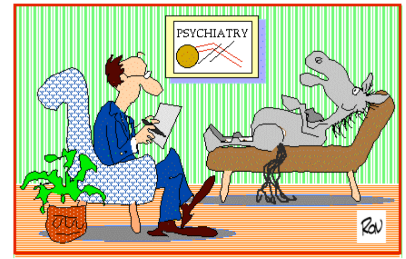


http://sohowww.nascom.nasa.gov/data/realtime/eit_304/512/

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

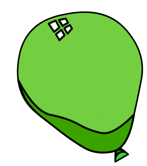
Why is the Sun Stable?

- What keeps gravity from collapsing the Sun?
- What keeps the Sun from exploding?

Pressure

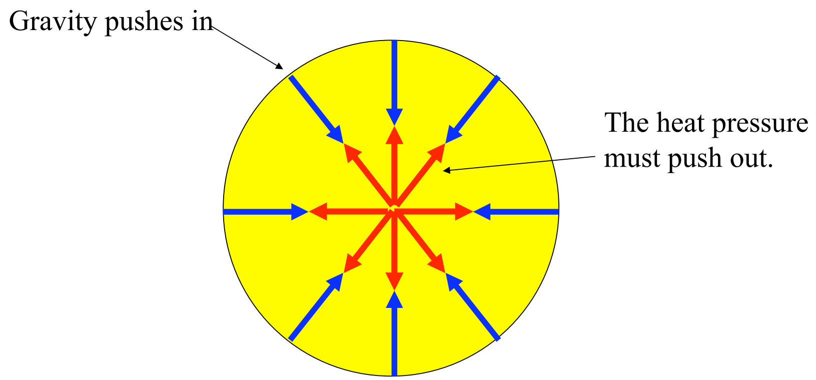
- What is pressure?
  - $\text{Pressure} = \dfrac{Force}{Area}$
- Explain blowing up a balloon?

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



- http://www.phys.hawaii.edu/~teb/java/ntnujava/idealGas/idealGas.html

The Battle between Gravity and Pressure



Hydrostatic equilibrium: Balanced forces

Question

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

a) Keeps the Sun burning H into He.
b) Keeps the Sun from turning into a big cloud in the shape of a bunny.
c) Keeps the Sun a flattened disk.
d) Keeps the Sun a constant size.
e) Keeps the Sun unstable.