Astronomy 230

Section 1– MWF 1400-1450

106 B6 Eng Hall

<u>This Class (Lecture 10):</u>

Nature of Life

<u>Next Class:</u>

Nucleic Acids

Some Oral Presentation on Feb 16th and 18th!

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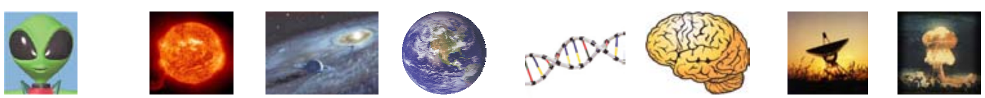
Outline

- Have to keep intelligent life in a rather limited range of temperature.
- Planetary habitable zones.
- What is n_e?
- Time to turn to life on Earth.
- What are the main properties of life?
- H, O, C, and N are the main elements of life. Why?
- Carbon has 4 bonding sites.

Drake Equation

Frank Drake



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

- N: # of advanced civilizations we can contact
- R_*: Rate of formation of Sun-like stars — **10** Stars/year
- f_p: Fraction of stars with planets — **0.34**
- n_e: # of Earthlike planets per system
- f_l: Fraction on which life arises
- f_i: Fraction that evolve intelligence
- f_c: Fraction that commun-icate
- L: Lifetime of advanced civilizations

Earth Chauvinism?

n_e

- Complex term, so let's break it into two terms:
  - n_p: number of planets suitable for life per planetary system
  - f_s: fraction of stars whose properties are suitable for life to develop on one of its planets

$$n_e = n_p \times f_s$$

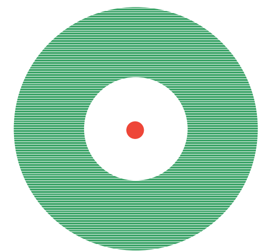
http://nike.cecs.csulb.edu/~kjlivio/Wallpapers/Planets%2001.jpg

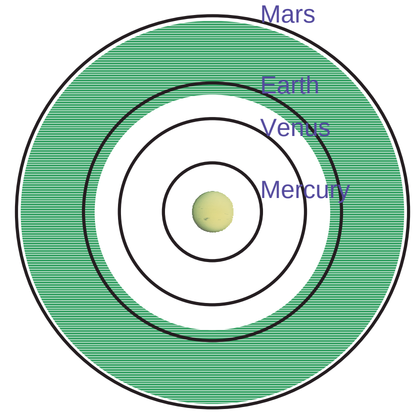
Keeping It Warm, but not too Warm

- What controls a planet's temperature?
  - The amount of light received from its star.
  - The amount of energy the planet reflects back.
  - And any Greenhouse effects of the planet.
    - Earth's effect raises its temperature by about 15%.
- Given a star's luminosity, a range of acceptable temperatures translates into a range of distances to the star.
- This range is called the star's habitable zone (HZ), as planets in this range we have temperatures suited for life.
- Only a rough guideline.

Habitable Zones– Are you in the Zone?

- Long living star
- Planets with stable orbits (thus stable temps)
- Liquid Water
- Heavy Elements– C, N, O, etc.
- Protection from UV radiation





Galactic Habitable Zone

- Likewise, the galaxy has regions that are better suited to life.
- In the inner regions of our galaxy, supernovae are too frequent.
- In the outer regions, there are too few metals.

http://www.prazen.com/cori/galaxy.jpg

The Sun's Variation

- As the Sun ages, it gets slightly brighter.
- When it was younger, its luminosity was 70% current values.
- A young Earth should have been 20K colder– iceball!
- For example, during our ice ages, the temperature only changed by about 1%.

http://www.soest.hawaii.edu/gerard/GG108/images/bylot.jpg

The Sun's Variation

- There is evidence that the Earth did freeze nearly over– 2.8 billion years ago and 700 million years ago, probably from changes in the Greenhouse gases.
- This implies that the habitable zone can vary with time, thus the real habitable zone is smaller than shown before.
- Some have postulated that real zone is only 0.95 to 1.01 AU! If the Earth were 1% farther away– Iceballed. And n_p would be very small ~ 0.1.

http://www.cnn.com/2000/TECH/space/01/19/iceballs/

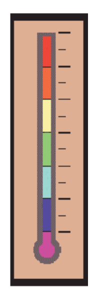
Earth's Atmosphere

- Most recent studies suggest a feedback mechanism.
- CO_2 cycles from atmosphere and oceans (buried sedimentary carbonate rock).
- Carbon is then released by volcanoes.
- CO_2 is removed by the weathering of rocks, allowing reactions.
- Negative feedback process
  - Increase in temperature: evaporation of oceans, more rainfall, more weathering and CO_2 reduction, so decrease in temperature.

http://www.wildtech.org/images/feedback.gif

Life Adds to Feedback

- Life increases the weathering of rock.
- J.E. Lovelock has proposed that life itself stabilizes the planet temperature.
- Regardless, the negative feedback helps with the habitable zone, so we can estimate perhaps n_p is around 1– more Earth chauvinism?



Optimism?

- Carl Sagan argues for $n_p > 3$.
  - If Venus had less clouds (less greenhouse) it could have been cool enough for life.
  - If Mars had a thicker atmosphere (more greenhouse) it could have been warm enough for life.
  - If solvents other than water were used, maybe the moons of the outer planets?
  - Giant Jupiter-like planets close in?

Pessimism?

- We only considered temperature. What about:
  - Gravity
  - Atmospheric pressure?
  - Size of the moon or planet?
  - Does life need a Moon-like moon? Does life need the tides? Does the Moon protect the Earth's rotation? Is a Jupiter needed?
- If we impose Earth chauvinism, we can reduce $n_p \sim 0.1$

http://sagiru.tripod.com/Travel/Lost_in_the_Sahara/lost_in_the_sahara

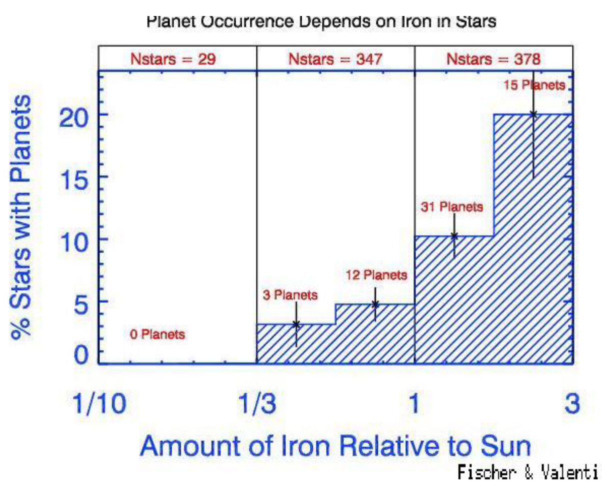
n_p

- Can range from 0.01 to 3+.
- Let's vote!
- In this class, let's assume a value n_p = ?

- So what about this f_s: fraction of stars whose properties are suitable for life to develop on one of its planets

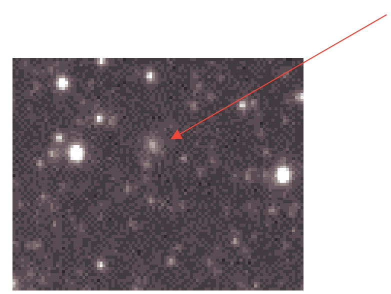
Differences of Stars to Life

1. Metals. Stars with heavy elements, probably more likely to have planets. Suggested in the current planet searches.



Differences of Stars to Life

2. Main sequence lifetime of star. Need the brightness to stay as constant as possible. Otherwise the temperature changes dramatically on the planets.
3. Time on the main sequence. Again, we need temperature stability for at least 5×10^9 years. This rules out stars more massive than 1.25 solar masses! Good news is that still leaves 90% of all stars.



Differences of Stars to Life

4. Minimum mass of star. If ice exists close to the star, that would imply the formation of Jupiter-like planets not Earth-like planets. And, any life bearing planet would have to be closer to the star– and closer to stellar effects (e.g. tidal locking and more flares from low mass stars). That limits us to about 0.5 solar masses, leaving about 25% to 50% of all stars.
5. Binarity. Planets may form. But they may have odd orbits unless the 2 stars are far apart or it orbits the binary.

Adding it all up

Stellar Requirement	***Mass Limit***	***Fraction OK***	***Cumulative Fraction***
Heavy Elements	…	0.9	0.9
Main Sequence	…	0.99	0.891
Main Sequence Lifetime	$M < 1.25\ M_{sun}$	0.90	0.890
Synchronous Rotation/ Flares	$M > 0.5\ M_{Sun}$	0.25	0.200
Not a Binary	…	0.30	0.060
Wide Binary Separation	…	0.50	0.1

f_s

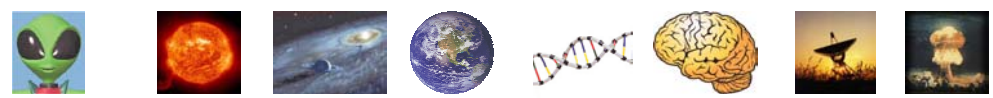
- Can range from 0.06 to ?.
- Let's vote!
- In this class, let's assume a value f_s = ?

Then, we can estimate n_e

$n_e = n_p \times f_s = ? \times ? = ?$

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	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
	10	**0.34**	**?**				
	Stars/year		Planets/system				

So Far, We have Studied

- The Universe
  - Big Bang
    - Creation of hydrogen, helium…
  - Galaxy formation
    - Swirls of elements embedded in self-gravitating cloud of dark matter
  - Star birth
    - Energy generation and element production in self-gravitating mass of gas
  - Planets
    - Ice, rock, gas surrounding star form planetesimals, then planets

Life on Earth

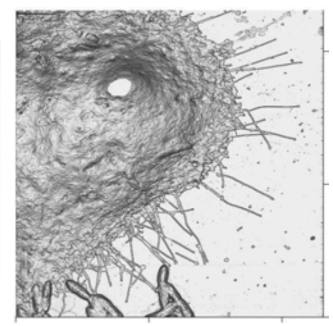
- Time to examine terrestrial evolution.
- Need to understand what is needed for life to arise.
- Again, some Earth chauvinism.
- Relies on chemical evolution
- Eventually life began?
- In our scientific approach, we look at life as a result of chemical evolution of complexity.
- We will view the formation of "life" on planets as we did star formation
  - A natural consequence of natural laws
  - More specifically, as a consequence of the complex chemistry that is sometimes achieved.

Cosmic Imperative?

- But is life a cosmic imperative?
- Just like gas forms galaxies, and in galaxies stars and planets form, do chemicals on some planets form molecules that lead to life?

All Made from the Same Stuff






Element Basis of Life

- About 95% of the mass of all terrestrial organisms is composed of only 4 out of 90 elements
  - Hydrogen (61% in humans)
  - Oxygen (26% in humans)
  - Carbon (10.5% in humans)
  - Nitrogen (2.4% in humans)

- HOCN is essential to life and it is common in space.

Trace Elements

In addition to HOCN, there are some other elements that are essential for life but in *smaller* amounts:

- Sulfur, magnesium, chlorine, potassium, sodium
  - These other elements make up about 1% of mass of living organisms
  - Exist in roughly the same concentration in organisms as in ocean water
  - Highly suggestive that life began in oceans
  - Furthermore suggests that the evolutionary processes occurred on Earth. Panspermia problems?

Good News

- H,O,C,N very common in universe everywhere as far as we can tell
  - If life were based totally on rare elements, we might expect its occurrence to be more rare…
- So, we expect ET life to be based primarily on HOCN. The four primary chemical elements of life with some other simple components can produce staggering complexity.
- But, each planet will feature its own environment of trace elements giving each planet's life a unique twist to the standard HOCN chemistry

Nature's Complexity

- The workings of biological molecules are an absolute marvel
  - How did this complexity develop?
  - How did it evolve?
- As complex and mysterious as life on Earth may be, we can begin understand it
- Start with the basics:
  - Why are H,O,C,N the basis for living organisms?
  - How do the molecules formed by these (and other elements) work to make DNA, proteins, life?

Special Stuff?

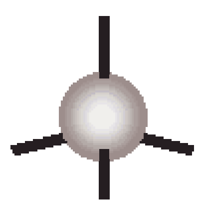
- Why is Earth life based on H,O,C,N instead of the more abundant elements found on Earth?
  - Suggests that the formation of life is not able to be formed just out of anything lying around.
  - The selection of H,C,N,O seems to be a necessity of the chemistry of life.
  - In general Earth life is a carbon based life. Carbon is the main backbone of the chemistry.
- Is this good news?

Why Carbon Based Life?

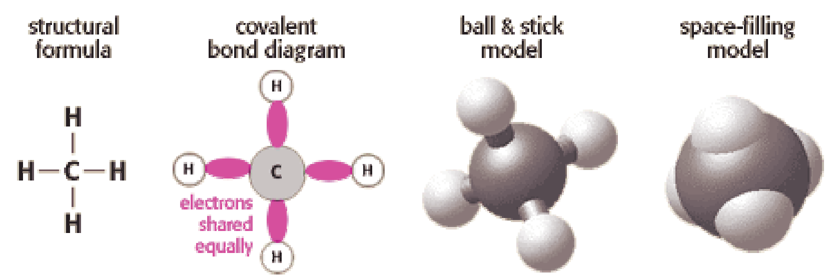
- Carbon's electronic structure allows it to form long chains
  - Chains of atoms and chains of molecules– complexity
  - Life needs bonds to be stable but breakable
- Good for us, at temperatures at which water is liquid, carbon bonds are stable but breakable
- Organic chemistry is the special branch devoted to carbon chemistry.

Bond, Carbon Bond

- Carbon has 6 protons, 6 neutrons, and 6 electrons
  - Electrons distribute themselves in "shells"
    - Pauli exclusion principle
    - 1^{st} (inner-most) shell is filled by 2 electrons
    - The 2^{nd} shell would be 'filled' by 8 electrons, but its only got 4
      - So, Carbon has 2 electrons in inner shell and 4 in 2nd shell
      - It likes to bonds to "fill" second shell by sharing with four other electrons



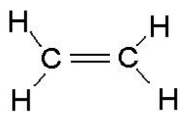
The Bond– Methane

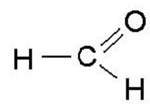


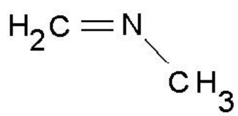
Not many other elements can share 4 bonds.
Silicon, which is much more abundant, can.

http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/page2.html

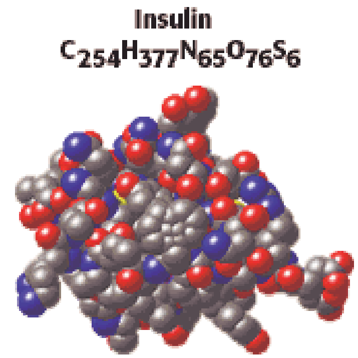
More Bonds







And More



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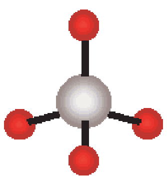
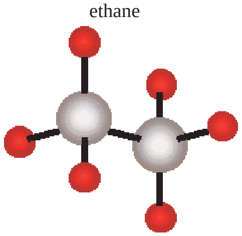
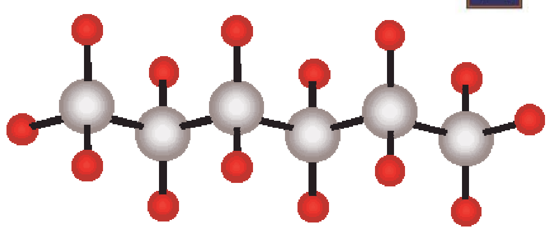
Bonding Variation



methane

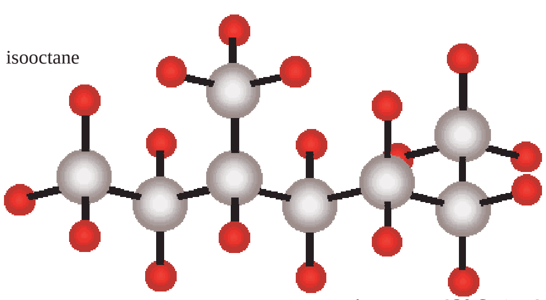
ethane



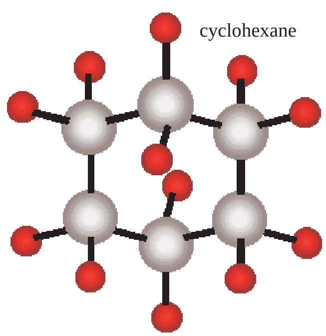


hexane

isooctane



cyclohexane



Unique?

- As far as we know, the complexity of terrestrial biochemistry can only be achieved with carbon-based polymers
  - Especially considering the need for liquid water
    - Which puts restrictions on the temperature in which the chemical reactions occur

Nitrogen

- Actually play central role in organic chemistry.
- It is prominent in biological compounds due to its reactivity with carbon and its propensity to form chains in organic compounds

Molecular Basis of Life

- Great diversity of Life on Earth, but still it is 70% water and 24% four large molecules:
  – Proteins
  – Nucleic Acids
  – Lipids
  – Carbohydrates

- Not completely true. The simplest life, viruses, can have a single molecule of nucleic acid surrounded by a protein coating.