Astronomy 330:

Extraterrestrial Life

This class (Lecture 19):

Origin of Life

Next Class:

Transition to Life

Drake Equation

That's 45.1 Life-liking systems/year

Frank Drake

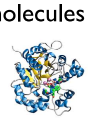
$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

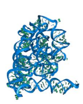
N	R*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	30 stars/yr	0.8 systems/star	4 X 0.47 = 1.88 planets/system	life/planet	intel./life	comm./intel.	yrs/comm.

The next term in the Drake equation is fl. Arguably the hardest term to estimate. We do not know much about the early Earth as we do not have the rock from that time period— too much processing by seismic activity. Nonetheless, we can make develop likely pathways for life, then try to draw conclusions from those arguments. One of the difficult thing here is that we will mostly be examining modern life— not early life. We are looking at the perfected machinery of life, but early life may have been very different. We skip ahead to the top of the line best designed (by evolution) car— sports car, and we do not see the first steps of develop of cars— the first car was slow, clunky, and less efficient, likely just like early life. So although modern life looks like it has too many fine-tuned parameters to have ever happened through the mechanisms we will discuss, remember we are skipping ahead to the Ferrari, by-passing the first Benz.

Molecular Basis

Two molecules essential for Life:

 Proteins

 Nucleic Acids

Both are polymers

Proteins and Nucleic Acid are closely linked at some fundamental level.

Did proteins evolve first and produce nucleic acids, or vice-versa?

Chemical Evolution of Life

1. Atoms needed are H,O,N, and C with small amounts of P and S.

2. Two basic molecules are essential for life: proteins and nucleic acids

3. Both are polymers– made of simpler monomers that make up the "alphabet" or code of life. These direct the transcription and translation of the proteins from the code.

4. Proteins and nucleic acids are closely linked at a fundamental level. Communicating through the genetic code that must have originated very early. In most cases, the same code is used by different messages for chicken or shark or human or even Elvis.

5, Because of #4, protein synthesis must be directed by nucleic acids, but nucleic acid transcription requires enzymes (proteins). Chicken or the egg problem? Did proteins arise on Earth first and give rise to nucleic acids, or vice versa?

This is the question of how life arose on Earth.. which is hard to crack.. pun intended.

Origin of Life

Fossil Evidence implies life evolved when Earth was ~ 700 million years old (3.8 billion years ago).

Approximately when heavy bombardment ended.

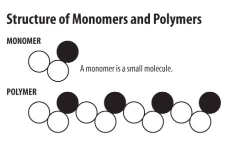
Thus, life arose quickly: 10-100 million years ago from *Sterile Planet* to *Party Town*!

Bricks to Structures

Monomer: → Polymer:

Amino Acids → Proteins

Sugar, Phosphate, Nitrogenous Bases → Nucleic Acids



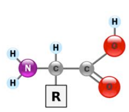
Reminder that life is comprised of 2 main polymers — proteins (made up out of amino acids in specific sequences) and nucleic acids (made up of sugars, phosphates, and bases) Life requires proteins (and enzymes a type of protein) to operate. Our bodies know how to construct the proteins needed for day-to-day life by having a dictionay of how to spell the order of amino acids to equal a protein. That order is stored in the bases of the nucleic acid. Three bases encode an amino acid, and a certain string of these 3-pairs (can be 1000's) spell out a protein recipe.

Chemical Evolution

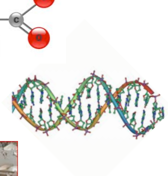
Evolutionary process appears to tend toward greater complexity

3 Steps in chemical evolution:

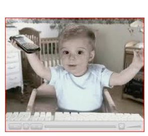
1) Synthesis of Monomers

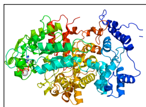


2) Synthesis of Polymers from the Monomers



3) Transition to Life





Origin of Life

Atoms needed: H O N C + P S

The crucial monomers:

Amino Acids: 20 needed for Proteins.

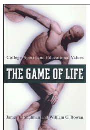
Sugar, Phosphate, Nitrogenous Bases for nucleic acid (DNA/RNA)

How did these molecules appear so quickly?

Early Earth (no fun):

- Poisonous Atmosphere
- Hot
- Lots of meteorites

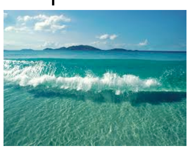
No DIRECTV



Synthesizing Monomers

What were the conditions when life began?

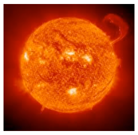
Liquid Water



Neutral or Slightly Reducing Atmosphere

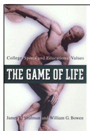
Sources of energy UV light, Lightning, geothermal

Some dry land.



Life arose under the following conditions

- Liquid water
- Some dry land
- Energy sources, including UV light, lightning, geothermal.
- A neutral or slightly reducing atmosphere (This is somewhat new). Remember no OXYGEN, mostly methane (CH_4) and CO_2.

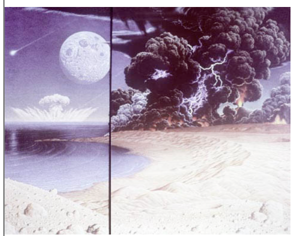


Reducing/Oxidizing?

Reducing Atmosphere: Contains elements that want to give up an electron.

Oxidizing Atmosphere: Contains elements that want to take an electron.

1 H (1.01)
8 O 15.99



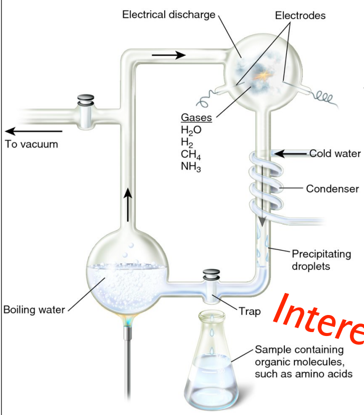
Reducing

CH_4, NH_3

Oxidizing

Neutral is neither.

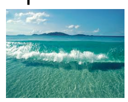
Miller & Urey Experiment



1953: Miller & Urey Experiment

Assume Reducing Atmosphere
CH_4, H_2, & NH_3

Liquid Water

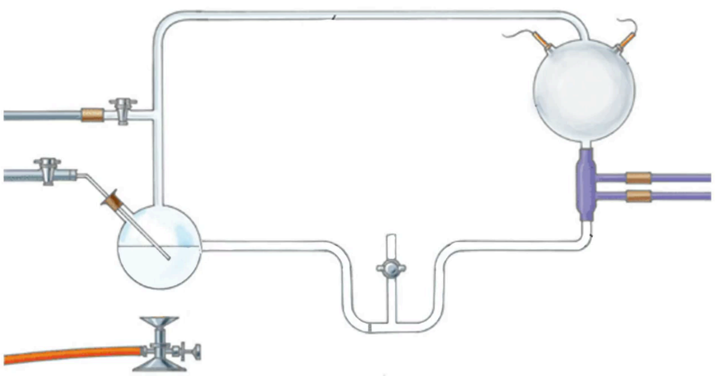


Sources of energy

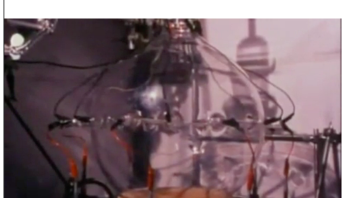
Interesting!

In 1953, Miller and Urey (UC) tried to duplicate conditions that they believed existed on the Early Earth– a heavily reducing atmosphere.
They Mixed CH4, H2, and NH3 gases in a flask for the atmosphere, and connected that to a flask with water for the oceans. A spark was used in the atmosphere flask to simulate lightning. They found interesting organic molecules in the "ocean".

Miller & Urey Experiment



Miller & Urey Experiment



4 Amino Acids formed along with some nucleotide bases and acetic acid.

Later work showed **ALL 20** amino acids necessary for life can be formed this way.

But, this does not directly produce monomers of nucleic acid.

and, the early Earth's atmosphere was not heavily reducing. Likely neutral or slightly reducing.

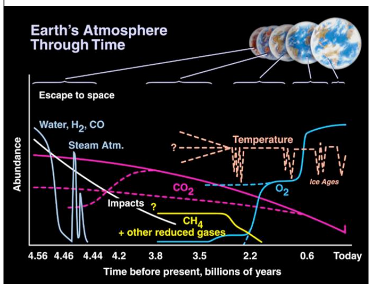
Legitimized scientific study of the *origin of life*

4 amino acids were made: glycine, alanine, aspartic acid, and glutamic acid. Also some nucleotide bases and acetic acid. Other experiments that went longer or with more of a reducing atmosphere or more lightning have been shown that ALL 20 amino acids needed for life can form in this way. Does not produce directly all monomers of nucleic acids, but intermediates were produced.

Early Monomers

How valid is the Miller & Urey Experiment?

The Miller & Urey Experiment did not directly produce monomers of nucleic acid



The early Earth's atmosphere was likely not heavily reducing, probably neutral or slightly reducing.

CO_2, N_2, & H_20

Uncertainty complicates the analysis, and still doesn't lead to *life*.

Early notions of methane-rich reducing atmosphere are wrong; Earth's early atmosphere was more likely CO2, N2, and H2O vapor. We still don't know early atmospheric composition well enough to make a stronger case. And we still don't know how this leads to DNA, the basis of all terrestrial life.

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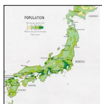
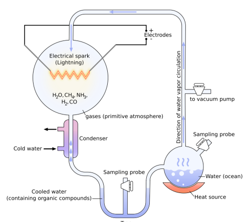


Early Monomers

More recent variants of the Miller & Urey Experiment have demonstrated that significant yields of amino acids can be produced in mildly reducing environments.



Summary:

1) We do not know how monomers arose on the early Earth.

2) We can conclude that many of the monomers can be produced in strongly reducing atmosphere.

3) Need other environments to make all monomers of life.

Still must forge polymers from the monomers!

We do not have a detailed theory of how all the monomers arose on the early Earth. General conclusion is that many of the monomers needed for life can be produced in a strongly reducing atmosphere, but that different environments are needed to get specific monomers. Don't forget that after the monomers are formed they MUST come together to form the polymers of life.

Question

Arguably, the most important legacy of the Miller-Urey experiment is that

a) we now know how some amino acids were formed on the early Earth.

b) it legitimized the scientific study of the origin of life.

c) it proved the early atmosphere was mostly methane.

d) somehow a glass flask was necessary.

e) None of the above.

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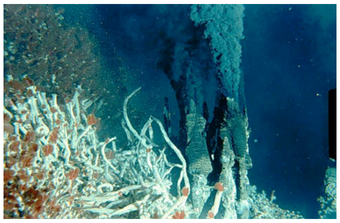
Life in other locales

Assuming we need a strongly reducing environment, maybe we look somewhere other than the atmosphere.



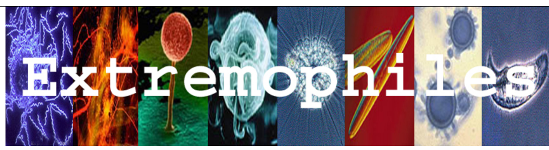
Undersea Vents

CH_4, NH_3, & SH_2

Interstellar Space

grist.org

Methane, Ammonia, and other energy-rich molecules like hydrogen sulfide. Circumstellar disks, where planets are born, are reducing environment with charged particles and maybe even lightning.

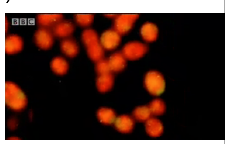


Microbes that live in extreme conditions.

Temperature Extremes (30 F to 212 F)

Tardigrade

Chemical Extremes
- Vinegar or Ammonia (< 5ph to > 9 ph)
- Highly salty (10x sea water)



Prime Candidates for ET life

Probably dominated life on young Earth

These are microbes that live in the most extreme places on Earth.

Temperature extremes
boiling or freezing, 1000C to -10C (212F to 30F)

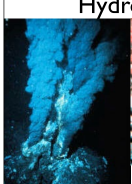
Chemical extremes
vinegar or ammonia (<5 pH or >9 pH)
highly salty, up to ten times sea water

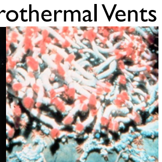
They are exciting, as they are the most likely candidate for extraterrestrial life. Probably dominated life on early Earth until fairly recently.

Tardigrades are really robust and have survived in space!

Extremophiles

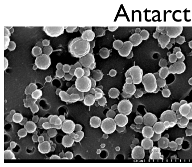
Hydrothermal Vents

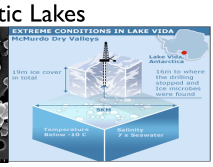




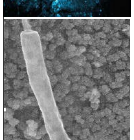
Tubeworms

Antarctic Lakes





Bacteria in aphotic, anoxic, acidic



Thermophilic bacteria

Hot Springs

Antarctic Dry Valley

Cryptoendoliths

Found in all the harsh locations on Earth. From the deepest ocean, to under ice sheets in below freezing water, to hot sprains, ro the driest place on Earth.

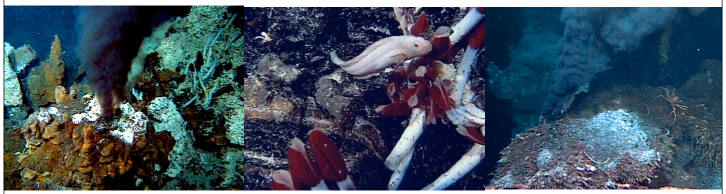
Undersea Vents

Miles below ocean surface, life exists.

Undersea Hydrothermal Vents (Black Smokers)

Vents spew mineral-laden superheated water.

No photo-synthesis, so does life survive?



This is life that does not need the Sun at all, which we used to think was impossible.

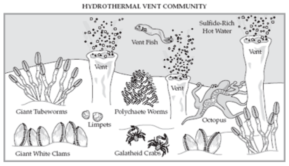
http://www.pbs.org/wgbh/nova/nature/life-in-the-abyss.html

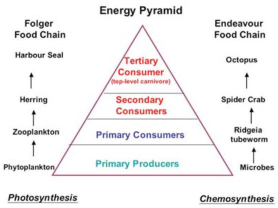
Undersea Vents

Chemosynthesis: Chemical Reactions to produce food.

Base of the food chain: bacteria

Life eats Bacteria, life eats the life that eats the bacteria, and so on ...

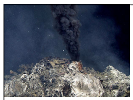




Symbiosis

Chemical reactions or chemosynthesis to produce food instead of the Sun. Some life is bacteria, some eat the bacteria, some eat those that eat the bacteria, and some have bacteria inside them in a symbiotic relationship.

oceanlink.island.net
mdk12.org



Hot Origin Theory

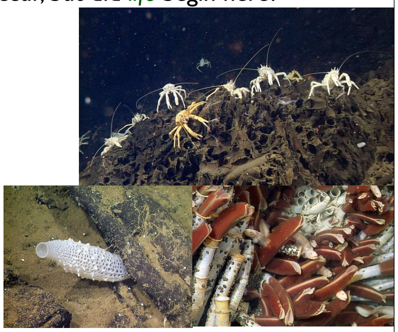
Food chain that does not rely on the Sun.

Pre-biotic synthesis can occur, but did *life* begin here?

Problems:

1) Existing vents are short-lived (few decades)

2) Existing vents are HOT, would life survive here, or be destroyed?



Vents are examples of a food chain that does not rely ultimately on photosynthesis. Demonstrates that pre-biotic synthesis can occur, but did life begin there? And current vents are short-lived- a few decades. And hot- if synthesis first occurred there, it might have been quickly destroyed. Bad news for Europa?

Hot Origins Theory

Life is common in Hot Environments:

- Hot Springs (Yellowstone)
- Hot Oil Reservoir (up to 2 miles underground)

How old are these organisms? Origins?

Or did life start somewhere else and migrate there?

Many of those organism display old genetic characteristics, but some say not ancient enough.

Seems more likely that life started somewhere cushy (like Urbana), then slowly evolved into extremophiles, but we do not knoq.

Interstellar Space

A circumstellar disk is also a reducing atmosphere.

Complex molecules have been observed in space.

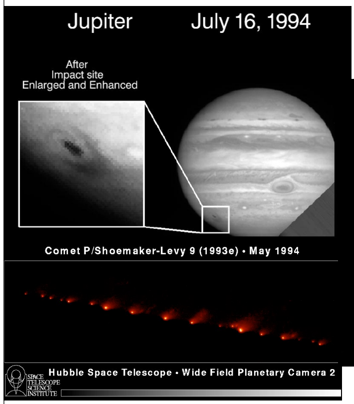
Organic ices survive past the frost line.

Comet Hale-Bopp (1997)

Comets could transport organic compounds to Earth.

Another reducing atmosphere is space and the circumstellar disk from which our solar system formed. We have seen complex molecules in space. The ices would have been destroyed this close to the Sun, but farther out would have been fine. Comets could transport the molecular binding dust grains back to the Earth.

Comet Collision



Are comets really a possibility?

www.youtube.com/watch?v=tbhT6KbHvZ8

Comets

Comets hit planets, and the rate was higher in the past

Creation of Amino Acids from Cosmic Rays.

Creation of Amino Acids during impact event.

~5% of comets are carbonaceous chondrites, which contain organic compounds including Amino Acids.

Panspermia

Have similarities to interstellar ices. Comets hit the Earth, and did so much more often in the past. About 5% of comets are carbonaceous chondrites, which contain about 1-2% of their mass in organic compounds, including amino acids of non-biological origins (e.g. the Murchison meteorite). Can life get transported? Panspermia again.

Question

Which of the following is not a way that life's monomers might have formed on early Earth?

a) Hot vents at the bottom of the ocean.

b) In thunderstorms in the Oxygen rich atmosphere.

c) In the oceans, using energy sources and the early atmosphere of Earth (assuming reducing atmosphere).

d) From comets landing on Earth.

e) Debris from the early circumstellar disk (which had a reducing atmosphere).

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So?

What was the origin of monomers needed for life?

We do not know!

A number of possibilities exist:

Earth's early atmosphere

Near hydrothermal vents

In interstellar space