Astronomy 230

Section 1– MWF 1400-1450
106 B1 Eng Hall

This Class (Lecture 18):

Origin of Life— Part 2

HW#4 Due on Oct 11th

Midterm On Oct 15th!

Next Class:

Alternatives

Music: *We Are Made of Stars* – Moby

Outline

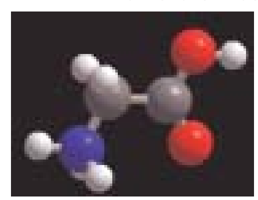
- Origin of life?
- Early monomers
  - Formed in the atmosphere?
  - Around hydrothermal vents?
  - In space?
- Early polymers ?
- Early Nucleic acids ??

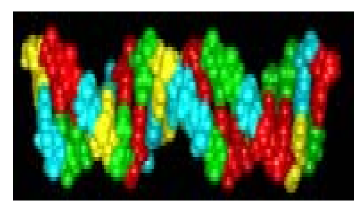
Life

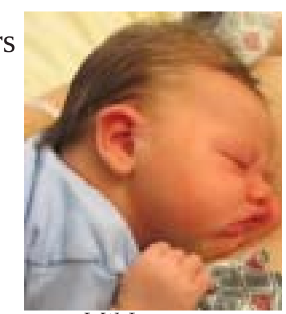
- The most crucial monomers required for life are:
  - Amino acids (20 flavors) for **proteins**
  - The nucleotides: sugar, phosphates, and nitrogenous bases for **DNA/RNA**.
- How did they occur in a useful configuration so **fast** on the early Earth?
  - Remember the early Earth is not a fun place.
    - Poisonous gas atmosphere, hot, lots of meteorites, and cable TV is still 3.8 billion years away.

Chemical Evolution

- Chemical basis of life obviously crucial.
- Apparently evolution of life is a continuation of tendencies toward greater complexity
- Chemical evolution has 3 steps:
  - Synthesis of monomers
  - Synthesis of polymers from the monomers
  - Transition to life.







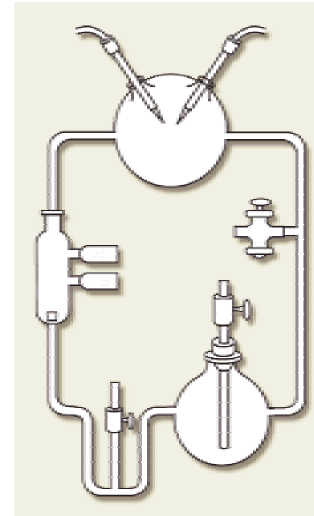
Synthesis of Monomers

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

http://origins.jpl.nasa.gov/habitable-planets/images/ra6-early-earth-th.jpg

Miller and Urey Experiment

- In 1953, Miller and Urey (UC) tried to duplicate conditions that they believed existed on the Early Earth– a heavily reducing atmosphere.
- They Mixed CH_4, H_2, and NH_3 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".



http://www.vobs.at/bio/evol/e05-millerurey.htm

Miller and Urey Experiment

- 4 amino acids were made: glycine, alanine, aspartic acid, and glutamic acid. Also some nucleotide bases and acetic acid.
- It has been shown that <u>ALL</u> 20 amino acids needed for life can form in this way.
- http://www.ucsd.tv/miller-urey/
- Does not produce directly all monomers of nucleic acids, but intermediates were produced.

http://physicalsciences.ucsd.edu/news_articles/miller-urey-resurrected051903.htm

Early 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.

Early Monomers

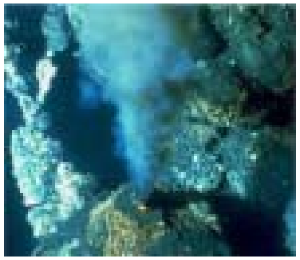
- Still, the Miller-Urey experiment legitimized the scientific study of life. The production of amino acids under the presumed conditions of the early Earth was exciting.
- But the assumptions of the experiment have been questioned.
  - Early notions of methane-rich reducing atmosphere are wrong
  - We still don't know early atmospheric composition well enough to make stronger case
  - We still don't know how this leads to DNA, the basis of all terrestrial life
- Recently, a group in Japan has showed that with enough energy, you can still get significant yields of amino acids in a mildly reducing environment.

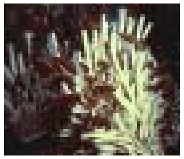
Other places

- Maybe if we require (still not sure) a strongly reducing environment, we have to look elsewhere.
  - Area around undersea hot vents, some of which have CH_4, NH_3, and other energy-rich molecules like hydrogen sulfide.
  - Interstellar space.

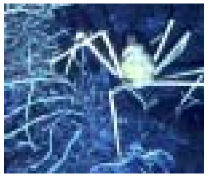
http://www.noaanews.noaa.gov/magazine/stories/mag114.htm

http://www.chl.chalmers.se/~numa/photo/keyhole-small.jpg





The Underwater Vents



- Miles below the ocean surface, life lives on the edge! Places were sunlight never reaches.
- From regions of volcanic spreading of the floor, hydrothermal vents or black smokers, underwater geysers, spew mineral-rich superheated water.
- No plant life, but life thrives. So what does life live on?
- 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.

The Hot Origins Theory

- Vents are rare 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.
- But live is common in hot environments
  - Hot Springs (like in Yellowstone)
  - Hot oil reservoirs up to 2 miles underground.

- Many of those organism display old genetic characteristics, but some say not ancient enough.
- Did life start somewhere cushy and move there?

Interstellar Space

- 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.

http://stardust.jpl.nasa.gov/science/images/pach7.jpg

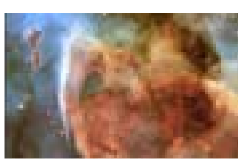
Comets

- 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.

http://stardust.jpl.nasa.gov/science/images/num2.jpg

So?

- We don't know the origin of the monomers that are needed for life.
- But, there are a variety of processes that could produce them.
  - In Earth's early atmosphere
  - Near hydrothermal vents
  - In interstellar space
- The next step is polymerization



http://origins.jpl.nasa.gov/habitable-planets/images/ra6-early-earth-th.jpg

Synthesis of Polymers

- If we assume that the early monomers for proteins and nucleic acids existed on the early Earth, then is it plausible that they would polymerize?
- The standard idea of the prebiotic soup would suggest that it is easy to form polymers, but not so fast.
- The problem is that the separate monomers are a lower energy state. They like to be separate.
- It's an uphill battle for the early monomers to turn into polymers.

http://www.heartsong3.com/Images%202000/Uphill.jpg

Polymer Pressure

- Hmm.. Does this mean that the key polymers that keep us alive are intrinsically unstable?
- Yes. Sort of kinda.
- But, we are constantly inputting energy into the system– our body. Some better food than others.
- A simple pattern: simple components + energy leads to greater complexity
- But for early life, the problem was for polymers to stay together.
- Even water helped pull them apart.

Making Them Hook Up.

- One idea is for the early soup to quickly evaporate into a condensed soup– so the monomers can join up.
- Another idea, is to find an energy producing reaction that promotes polymerization.
  - Energy currency in life now is ATP (adenosine triphosphate), which is an adenine base, a ribose sugar, and a tail of 3 phosphates. The phosphates bonds are broken to provide energy and allow bonding.
  - Too complicated for early life, but there are other similar molecules that could do a similar job. Maybe produced in a Miller-Urey procedure?

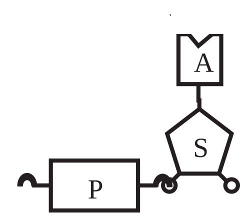
http://www.physics.uc.edu/~hanson/ASTRO/LECTURENOTES/ET/Earth2/PrimordialSoup2.jpg

Hooking up Dirty

- Another possibility for polymerization is in clay soils.
- Clay has layers of silicates and water.
- Add water, the layers expand and amino acids can move between layers.
- Remove water, the layers contract and the amino acids get absorbed onto the clay surfaces. Sort of like dust grains in space.
- Experiments have shown that certain clays, promote polymerization of 50 or more amino acids chains with high efficiency.
- Add water, and the polymers are released.
- Think of the ocean tides fueling the polymerization.

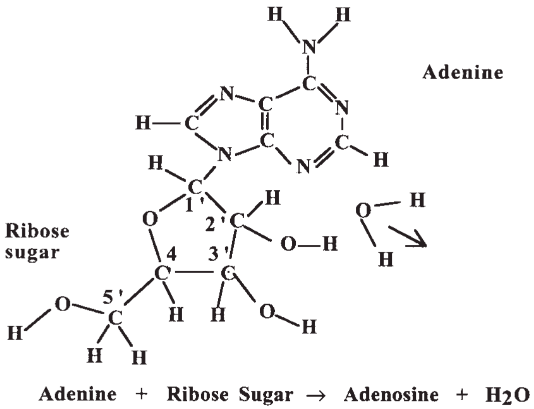
So… And RNA/DNA?

- There are a few ways that amino acids can hook-up and form polymers, but nucleic acids are more difficult to understand as they are more complex.
- What is the basic monomer of RNA or DNA?
- Remember the building blocks are:
  - Sugars
  - Phosphates
  - Bases
- So, one of each is a nucleotide



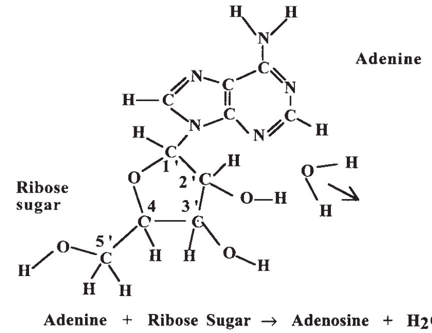
Nucleoside Synthesis

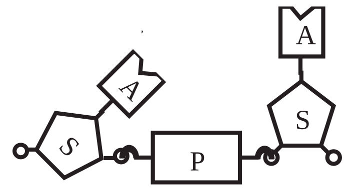
- Not well understood.
- Can number the carbon atoms in the ribose sugar.
- It is essential that the base attach at the number 1 carbon only. Otherwise, it is not a nucleoside.
- The base can attach at the 2 or 3 carbon.
- Why was bond 1 preferred on the early Earth?



Phosphate Issues

- To make a nucleotide, the phosphates <u>must</u> then attach at the 3 and 5 carbons.
- In the lab, the phosphates tend to attach to the 2 and 5 carbons.
- This causes a misalignment, which prevents long stands.





Nucleotide Synthesis

- Nucleotide synthesis is not very efficient
- Heating ribose sugar with some purine bases can produce a few nucleotides, and salt can produce a better yield.
- So, again, maybe an evaporating pool with geothermal energy.
- But nucleotides with pyrimidine bases are more difficult.
- Some have argued for catalyst with metal ions can work.
- So, some ionized metals in the pool too?

http://www.themonkees.com/quizzes18.htm

Summary

- Polymerization of amino acids on the early Earth is plausible.
- Synthesis of nucleic acids seems to be much harder.
- Perhaps proteins from amino acid polymers played a role? Chicken came first?
- It is still more difficult, because life requires useful polymers. The order of the monomers determines the properties.

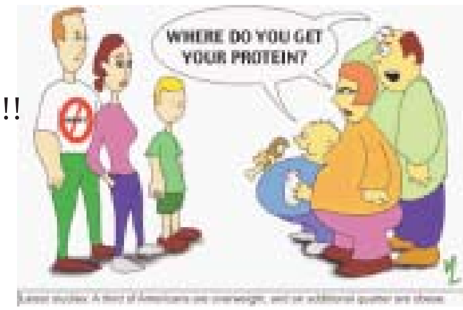
Protein Probability

- Seems easiest to produce a protein, so what is the chance of getting a useful protein with the proper order of amino acids from chance?
- Toss of a coin. 50/50 (or ½) chance of heads or tails.
  - If you want 10 heads in a role you can multiple the chance of 1 throw (½) times 1 throw (½) times…etc. or $(½)^{10}$ or 1 time out of 1024 attempts.

http://cruel.org/kitchen/shrunken.html

Probability of Randomly Forming Life?

- The polymer game is more complex with 20 options of amino acids so if random, the chance of getting a single amino acid is 1/20.
- For a protein with a specific 10 amino acids in order.
  - $(1/20)^{10}$ or about $1/10^{13}$ or 1 chance in 10 trillion!!!!



http://www.citypaper.net/hth/

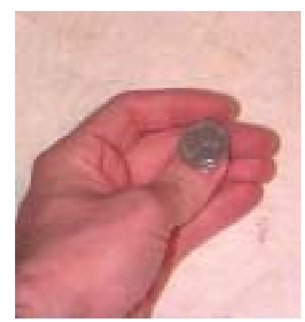
Getting Lucky?

- If we throw enough coins, we <u>will</u> get 10 heads in a row.
- And if there were very large numbers of monomers, then even a very unlikely event can happen.
- Perhaps **<u>time</u>** is the hero of the story?
- But, don't forget a typical protein can have easily more than 200 amino acids. That is a chance of success of $(1/20)^{200}$!
- A generous estimate of the number of trials that the early Earth had was about 10^{51}.

http://members.aol.com/LILAUTHOR1/hourglass.jpg

Pessimistic?

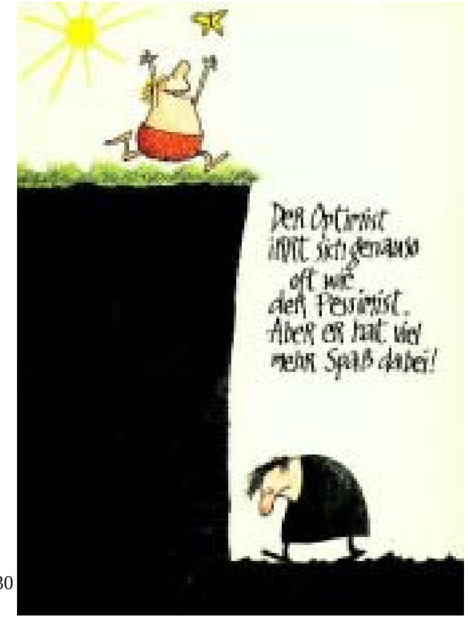
- But, maybe the early Earth only had a few amino acids at first. Then the odds are better for certain proteins.
- But, we require more than just 1 protein to be formed.
- And first life probably needed many proteins as well.



http://www.physics.brown.edu/Studies/Demo/solids/demos/1a2020.jpg

Pessimist?

- Bottom line is that we can not expect life to arise from completely random combinations of molecules to make more complicated molecules.
- Something else must play a role.
- Some proteins might have a preferred assembly.



Life – Gen Eds

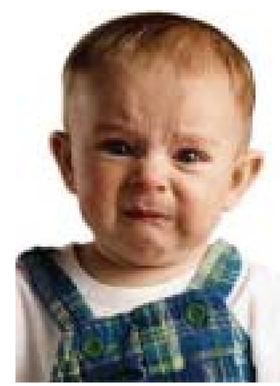
1. Precise way to reproduce instruction set (but not perfect)
2. Ability to control chemical reactions via catalysts.
3. A protective enclosure that separates the instructions and the catalysts from the environment. Becomes an individual not just a soup of chemicals
4. Method for acquiring and using energy.
5. Interconnections of the above.

Transition to Life?

- Really the big question.
- How difficult is it for the collection of polymers to become life?
- The last step in chemical evolution is really biological evolution.

Life

- Life is based on cells
  - Protective enclosures formed from lipids
- Cells contain nucleic acids and protein enzymes
  - Instructions and catalysts that allow replication of nucleic acids
- Methods for acquiring energy
  - Most organism now on Earth get energy from the Sun– either directly or indirectly. But that requires pigments.
  - Not sure if pigments were a primary need or if chemical sources of energy were used for early life.



http://www.internetcash.com/en/images/baby-crying.jpg

Transition to Life

- Two general categories
  - Primitive versions of proteins, nucleic acids, and protocells arose independently and combined to form a life form.
  - One of the components was dominant and the first "life" was based on only one polymer, then developed into life as we know it. We call it protolife.
- The statistical arguments made would argue <u>against</u> primitive life and <u>for</u> the protolife option.
  - Two protolife concepts based on <u>nucleic acids</u> or <u>proteins</u>.

http://www.perantivirus.com/sosvirus/graficos/bilgates.jpg

Protein Protolife?

- Sydney Fox experiment.
- By heating amino acids, droplets of protein formed when added to water– "proteinoids"
- Could have formed on the early Earth with tides.
- Sometimes they will grow and break into daughter spheres
- It is like cell reproduction, BUT there is no replication of nucleic acids ,so not true reproduction.
- Nonetheless, they might be suitable for protocells.

http://www.biology.iupui.edu/biocourses/N100H/ch19life.html

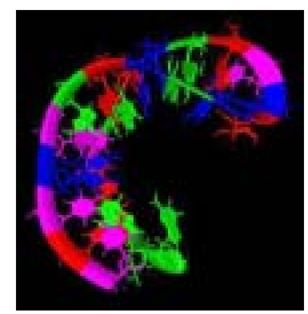
Protocells: Sydney Fox's Experiment

- Sydney argued that they formed a protolife that gradually became life as we know it.
- But how do nucleic acids come into play?
- Sydney argues that one microsphere developed the capability to make its own protein from amino acids, then passed that on to its "offspring".
- Then, nucleic acids might have been used to store the amino acid information.
- And only later took over– revolt of the bookkeepers!
- Most biologist do not like the idea, as life without nucleic acid is hard to accept.

http://vcl.ctrl-c.liu.se/vcl/Artists/Juan-Crespo/Sydney-Fox-Lz.jpg

The RNA World: Protolife

- The other camp believes that the transition to life was dominated by nucleic acids.
- This has clearly the opposite problems of the Sydney Fox scenario.
- These genes are naked!
- A ecosystem of self-replicating RNA is nice, but without capability for protein synthesis, they could do little else.
- However, it's the most widely accepted concept due to numerous experiments.



http://www.bizspacebiotechnology.com/rna1.htm

RNA World

- The idea is that RNA is mutating away– eventually one RNA develops an enzyme function.
- This evolves to fill many of the niches that today's enzymes perform.
- At some point, the RNA encode and produce proteins through amino acid encoding, using one of the RNA enzyme functions.
- This would make better enzymes that would replace the RNA versions.
- Is this possible?

RNA World Experiments

- Virus RNA is added to a test tube with replicase (an enzyme that catalyzes the synthesis of a complementary RNA molecule from an RNA template) and some activated nucleosides.
- The RNA was replicated without cell mechanisms.
- In one experiment, no RNA was added, and still RNA was produced.
- In fact, a number of variants were produced.
- The variant that replicated the fastest might win out.

Genetic Code and Origin of Translation

- One of the essential aspects of life is the synergistic interaction between proteins and nucleic acids.
- Chicken and egg problem still?
- If protein-like polymers of amino acids formed, they would have to polymerize the nucleotides.
- Then the resulting nucleic acid would have to direct the synthesis of more protein, leading to more of the nucleic acid. Etc.
- Or in some RNA world ribozymes began to construct the proteins– the favored view.

Neither Chicken nor Egg?

- While RNA world is favored, the difficulty is still in producing the nucleic acids on the early Earth.
- Freeman Dyson had argued that nucleic acid can not have been the first information carrying molecule.
- Transition between living and non-living requires a balance between order-preserving replication and error in replication.
- If too precise, nothing evolves.
- If too many errors, nothing consistent forms.
- He argues that RNA is not the easiest to start with, perhaps there were other polymers that preceded nucleic acids.

Alternatives: Clay

- Although the RNA world idea is widely accepted, there are issues concerning the the prebiotic chemistry.
- Clay based genetic systems.
  - Layers of impurities in clay can produce patterns.
  - The layers can separate, settle elsewhere, and grow.
  - The patterns are not perfectly copied.
- Would not have been a big deal, BUT clays can capture and help polymerize amino acids.
- Maybe there was clay based life?
- Eventually the proteins make nucleic acids, which then provides a parallel genetic system that disregards the clay.
- Bottom line is that the step from molecules to life is so great that we are far from understanding it.

Exotic Life

- We have spent a long time with Earth Chauvinism, but what if ET life is very different?
- If other options are possible then that will give a more optimistic value of f_l.
- As we just discussed, there are options for life based on other molecules than amino acids, some have been shown to sort of work in the lab.