Top Ten Reasons Why Your Ready for a Spring Break from Astro 330

10) It is officially Spring– vernal equinox is Sunday.
9) You're starting to enjoy seeing Frank Drake's face on my slides.
8) I'm starting to make sense.
7) Your friends complain that all you talk about is how closely proteins and nucleic acids are linked.
6) You sold your GPS and now navigate by the stars.
5) You celebrated Illinois Pluto Day on March 13th.
4) You can't form a sentence without using the term "freaky big".
3) You have subconsciously adopted a hairstyle matching Einstein's.
2) You wake up in cold sweats every night worrying about Supernovae.
1) You need to recover from the pneumonia you contracted while waiting for UFOs every night.

Astronomy 330

<u>This class (Lecture 17):</u>
Origin of Life
Daniel Cohen

<u>Next Class:</u>
Biological Evolution
Michael Hutchinson

HW 6 due tonight.

HW 7 is due March 31st

Music: *Space Robot Five*– Brave Saint Saturn

Presentations

- Daniel Cohen
  Music and Aliens

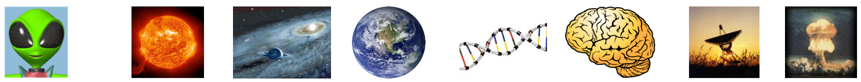
Outline

- How were the polymers made?
- Origin of Life on Earth?
  - RNA World
- Two types of cell life: Eukaryotes and Prokaryotes.

Drake Equation

That's 1.27 Life-liking systems/year

Frank Drake



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

# 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	0.65 systems/ star	1. 3 x 0.1 = 0.13 planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

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

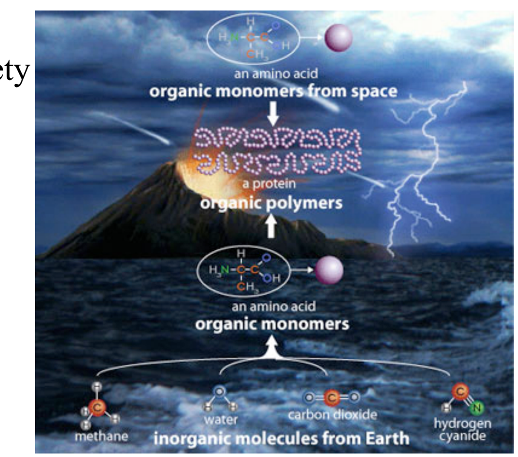
Comets

- 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

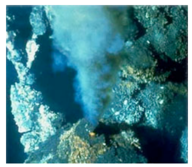
So?

- 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

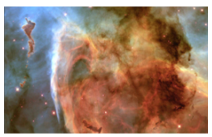


Next?

- The next step is polymerization.
- That is somewhat harder…..



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.

http://www.thanhniennews.com/society/?catid=3&newsid=6557

Polymer Pressure

- We are constantly inputting energy into the system– our body.
- A simple pattern: simple components + energy leads to greater complexity
- But for early life, the problem was for polymers to stay together, even water wanted to pull them apart.

http://www.thanhniennews.com/society/?catid=3&newsid=6557

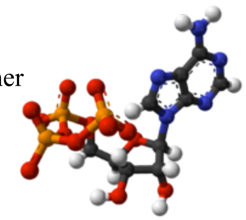
Making Them Hook Up.

- One idea is for the early soup to quickly evaporate into a condensed soup– so the monomers can join up.

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

Making Them Hook 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://en.wikipedia.org/wiki/Adenosine_triphosphate

Hooking up Dirty?

- Polymerization 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.

http://www.clw.csiro.au/education/soils/images/clay_soil.jpg

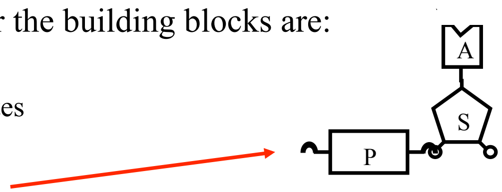
Totally Tidal

- 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?

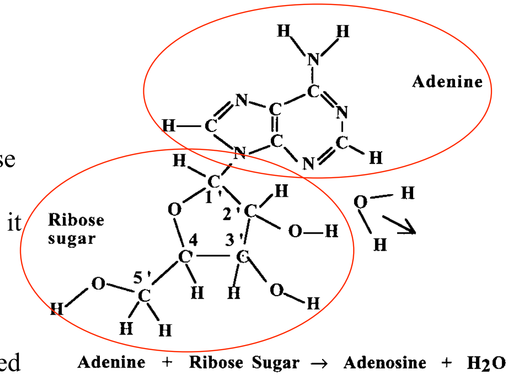
- There are a few ways that amino acids can hook-up and form polymers, but nucleic acids are more difficult to understand as they are more complex.
- What is the basic monomer of RNA or DNA?

- Remember the building blocks are:
  - Sugars
  - Phosphates
  - Bases



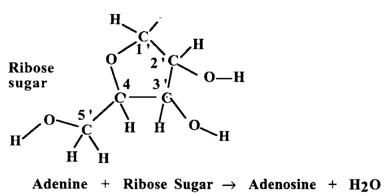
Synthesis?

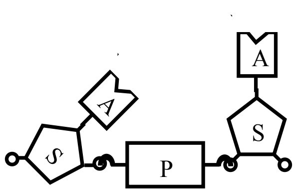
- Not well understood.
- Can number the carbon atoms in the ribose sugar.
  - It is essential that the base attach at the number 1 carbon only. Otherwise, it is not a nucleoside.
  - The base could attach at the 2 or 3 carbon too.
  - Why was bond 1 preferred on the early Earth?



Phosphate Issues

- And the phosphates **must** 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 – warped.





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.

Nucleotide Synthesis

- So, again, maybe an evaporating pool with geothermal energy– monkeys from the pool?
- 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

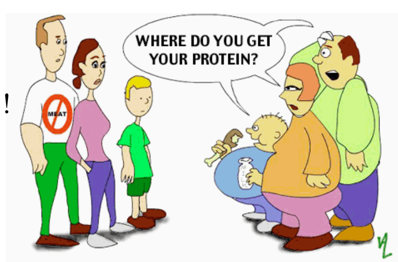
Protein Probability

- 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 row you can multiply 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!!!!



Latest studies: A third of Americans are overweight, and an additional quarter are obese.

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 **time** 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 $(1/20)^{200}$!

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

Pessimistic?

- A generous estimate of the number of trials that the early Earth had was about 10^{51}.
- 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?

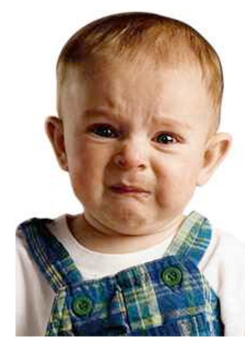
- Bottom line is that we can not expect life to arise from completely random combinations of molecules to make more complicated molecules.
- Something else must play a role.
- Some proteins might have a preferred assembly.

Poly 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.

Transition to 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 (e.g. chlorophyll).
  - Not sure if pigments are a primary need or if chemical sources of energy were used for early life.



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

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

- **Two possibilities**
  - Primitive versions of proteins, nucleic acids, and protocells arose independently and combined to form a life form, called **primitive life**.
  - 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 can call it **protolife**.
- The statistical argument would argue **against** primitive life and **for** protolife.

http://www.lbl.gov/Science-Articles/Archive/sb/July-2004/2_spinach.html

Transition to Life?

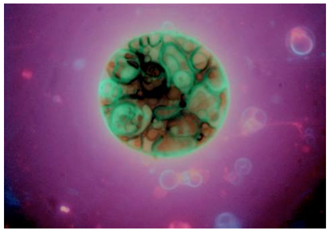
- Really the big question.
- How difficult is it for a collection of polymers to become life?
- The last step in chemical evolution is really biological evolution.

Protolife

If we assume that early life must have been protolife, then

– Two protolife concepts based on nucleic acids or proteins.

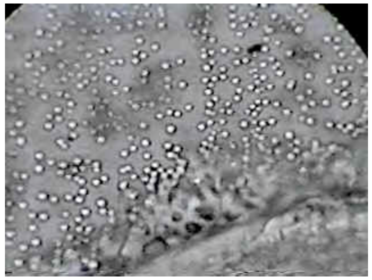
1. Protein life
2. RNA life



http://www.msnbc.msn.com/id/20249628/ns/technology_and_science-science/

1. Protein Protolife

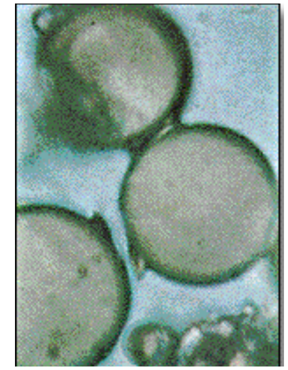
- Researcher Sydney Fox heated amino acids, and droplets of protein formed when added to water– “proteinoids”
- Could have formed on the early Earth with tides.



http://leiwenwu.tripod.com/primordials.htm

1. Protein Protolife

- 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

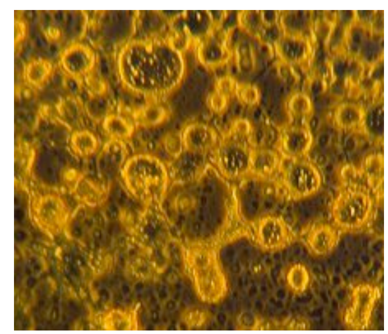
1. Protocells

- If so, how do nucleic acids come into play?
- Perhaps one proteinoid 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.

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

1. Protocells

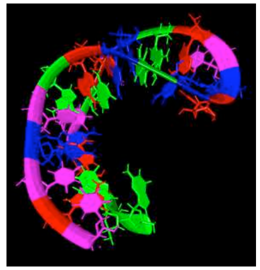
- And only later took over– revolt of the bookkeepers!
- Most biologist do not like the idea, as life without nucleic acid is hard to accept.



http://www.firstscience.com/home/articles/origins/genesis-by-comets-page-3-1_1383.html

2. The RNA World: Protolife

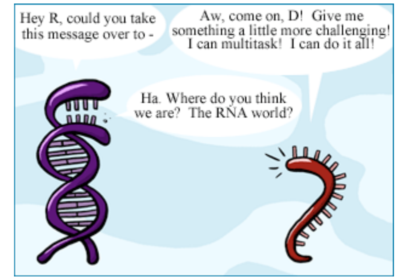
- The other camp believes that the transition to life was dominated by nucleic acids; the opposite problems of the Sydney Fox scenario.
- These genes are naked!
- A ecosystem of self-replicating RNA is nice, but without capability for protein synthesis, they could do little else.
- However, it's the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



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

2. The RNA World: Protolife

- The basic idea is that RNA did all the tasks.
- Both info storage and enzyme actions.
- Then, the DNA world evolved out of that.
- The rRNA encoding of proteins in today's world may be evolutionary left-overs.



http://evolution.berkeley.edu/evolibrary/images/interviews/rnaworld2.gif

2. RNA World

- 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, which would replace the RNA versions.
- Is this possible?

2. 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.
  - Although proteins were used in this experiment it is thought that RNA enzymes are what played the role on the early Earth.
- 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.

2. RNA World: Variations

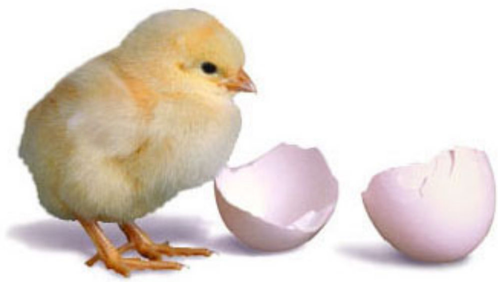
- Some think that RNA might not have been the first nucleic acid.
- On pre-biotic Earth maybe other nucleic acids were more easily formed at first.
- Some other nucleic acids include Peptide nucleic acid (PNA), Threose nucleic acid (TNA) or Glycerol nucleic acid (GNA).
- These would have been replaced with RNA later.

Genetic Code and Origin of Translation

- One of the essential aspects of life is the synergistic interaction between proteins and nucleic acids– still the Chicken and egg problem.
- If protein-like polymers of amino acids formed, they would have to polymerize (create) the nucleotides.
  - 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 (RNA enzymes) began to construct the proteins– the favored view.

Neither Chicken nor Egg?

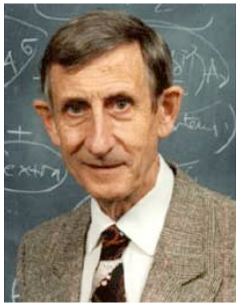
- While RNA world is favored, the difficulty is still in producing the nucleic acids on the early Earth in the first place.
- Freeman Dyson had argued that nucleic acid can not have been the first information carrying molecule.



http://www.antivegan.de/kochkurs/chicken-wings/chicken_egg2.jpg

Neither Chicken nor Egg?

- 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.



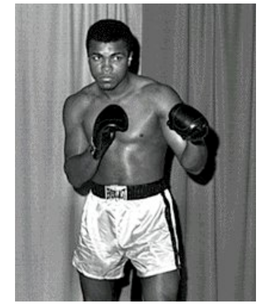
http://www.dartmouth.edu/~lhc/archive/sponsored/dyson.html

Alternatives: Clay

- Spontaneous life from non-living matter — abiogenesis
- 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.
  - In 2007, researchers concluded that the crystals were not faithful enough to transmit info from one generation to the next.

Alternatives: Clay

- 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.

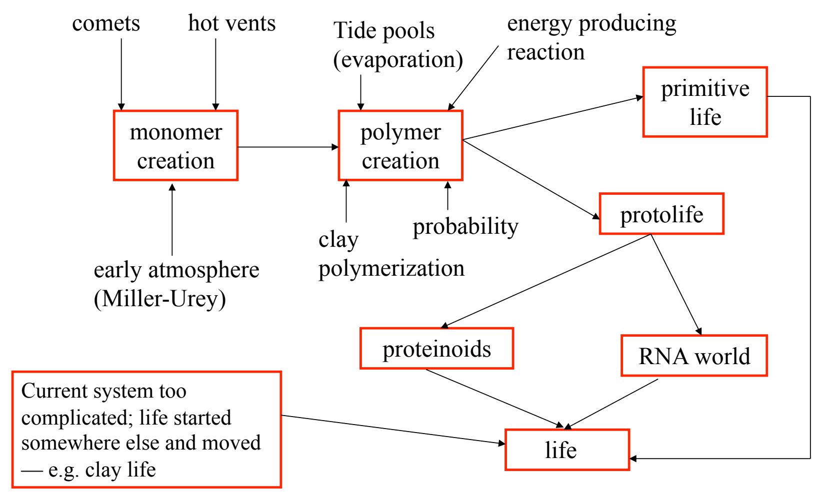


Question

We think the most likely path for life was

a) Life just arose with nucleic acid and proteins working together.
b) Life first started as a nucleic acid (RNA world).
c) Life first started as a nucleic acid (DNA world).
d) Life first started as a protein world.
e) Life first started as an amino acid world.

Pathways to Life on Earth



Question

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

a) Hot vents at the bottom of the ocean.
b) In a clay substrate.
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).

Pathways to Life on Earth

Okay, so we don't know how life on Earth started. We have some clues, but the details are unknown.

Life on Earth today after billions of year of evolution is very different than the first life.

So, we have to remember that although life as it is today is likely impossible at first, there was a quick way for life to start on this planet and evolved into life as we know it.

But would life on other planets have to follow our pathway?

— e.g. clay life

life

Exotic Life

- We have spent a long time with Earth Chauvinism, but ET life would be very different?
  Probably very alien!
- If other options are possible, then that gives 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.

http://www.itg.uiuc.edu/people/mcdowell/puppet-gallery/

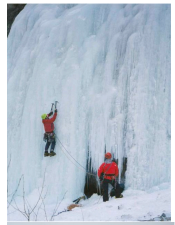
Silicon Based Life?

- Silicon makes 4 bonds like Carbon
- It is 135 times more abundant than carbon on Earth.
- But there are 4 arguments against it:
  - C-C bonds are twice as strong as Si-Si
  - Si-O or Si-H is stronger than Si-Si, so harder to make long stands
  - Si does not usually make multiple Si bonds
  - C with O makes CO_2, but Si with O makes silicates (SiO_2), which are large solid crystals.
- Still it is a possibility that can not be ruled out.

http://www.decipher.com/startrek/cardlists/mirrormirror/images/horta.gif
http://soundwavs.trekkieguy.com/25.html

Other Solvents

Molecule	*Freezes (K)*	*Boils (K)*
Water (H_2O)	273	373
Ammonia (NH_3)	195	240
Methyl alcohol (CH_3OH)	179	338
Methane (CH_4)	91	109
Ethane (C_2H_6)	90	184

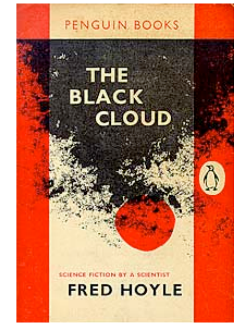


Water is about twice as good as ammonia or methyl alcohol. Water also has a high energy of vaporization, so it is very good at evaporative cooling (sweat).

http://www.talisman-activities.co.uk/winter/images/ice%20climbing.jpg
http://web.media.mit.edu/~fletcher/tags/boiling.jpg

Non-Chemical Life

Life is based on chemical energy. Thinking is an electrochemical activity. What about a life form that uses electromagnetic energy instead, perhaps without a body.



The Black Cloud (1957) by Fred Hoyle

The story describes a small interstellar molecule cloud that is alive. The organism is half a billion years old, as big as the orbit of Venus, and as massive as Jupiter. The brain is a complex network of molecules. Once it discovers the Earth it communicates with us:

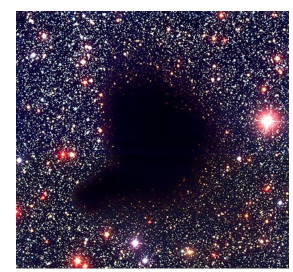
The Black Cloud Speaks

Paraphrased "badly"

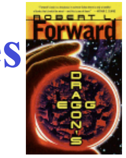
- It is most unusual to find animals with technical skills inhabiting planets
- Living on a planet, greatly limits your size, thus the scope of your neurological activity.
- Living on a planet, forces you to possess muscular structures to promote movements.
- Your very largest animals have been mostly bone and muscle with very little brain.
- One only expects intelligent life to exist in a diffuse gaseous medium. At the moment, I myself am building basic chemicals at about 10,000,000,000 times the rate as your whole planet.

Cloud Problems

- How would such a cloud evolve?
- The most dense clouds are 10^{13} times less dense than our atmosphere, which makes molecule interactions very rare.
- In space, interstellar clouds are torn apart in about 10^7 years. It took 10^9 years for intelligent life to form on Earth.
- Still it is a cute idea.



Other Voices, Other Energies



- Life based on nuclear energy (put forward by Drake)
  - Life on the surface of a neutron star?
  - Gravity and temperature too high for normal life.
  - Life made of closely packed nuclear matter instead of molecules
  - They interact quickly 10^{-21} seconds, much faster than chemical reactions.
- It has been fictionalized by Robert Forward in *Dragon's Egg*
  - Talking to these beings would be difficult.
  - Their Biology uses the strong nuclear force.
  - A time difference of a million to one.
  - In the time it takes to say "Hello" - would be the equivalent of a week to a star creature. It would hear "He . . . " on Sunday and ". . . lo" on the following Saturday.

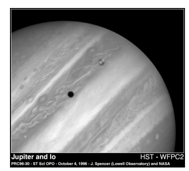
Or Too Big

- Life based on gravitational energy?
- In this creature, the gravity force would dominate– very large!
- The monomer of life would have to be a star.
- Perhaps individual stars play the role of individual atoms or molecules in Earth life.

Or Too Big

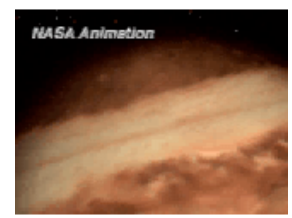
- Could galaxies be alive?
- Stars interact with one another on a time scale of many millions of years, so if life is to originate from such interactions it would take longer than the age of the Universe.
- If life is occurring, it is only at the stage where life was when the Earth was a few years old.

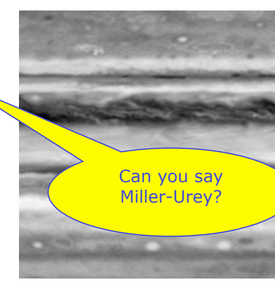
http://www.astro.cz/cz/wallpapers/index.php?id=15



Back to Jupiter's Atmosphere

- Although mostly gas, by 20,000 km in, the pressure is 3 million atmospheres!
- Due to an internal heat source, the temperature rises as one penetrates the atmosphere.
- The outer atmosphere is made of freezing clouds of ammonia, methane, and ice.
- The swirling patterns are evidence of great storms.



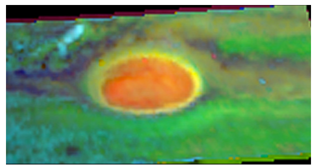


Can you say Miller-Urey?

Jupiter's Atmosphere

- The atmosphere resembles the conditions of the Miller-Urey experiment.
- The red bands and spots may be biological molecules.
  - The Miller-Urey experiment produces amino acids and **red polymers**.
  - Carl Sagan suggested that the atmosphere might be an optical photochemistry, like photosynthesis but more effective. Not much evidence for such a statement.
- But, constant churning of the atmosphere probably makes development of complex life nearly impossible.

Icy ammonia (light blue) discovered by Galileo



The Galileo Spacecraft (1989 – 2003)

How the main antenna *should* have looked

First atmospheric probe

Probing the Atmosphere

- The probe lasted for 57 minutes before it was destroyed by temperature and pressure.
- Found a lot of turbulence, strong winds (330 mph), very little water ice, and no lightning.

Probing the Atmosphere

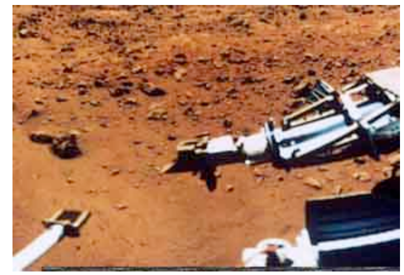
- Did not encounter the layers of clouds that was expected.
- The probe entered the least cloudy region of Jupiter.
- Did not rule out life, but did not support it.
- Later, the spacecraft Galileo was crashed into Jupiter.

What Did Galileo Experience?

- An atmosphere unlike Earth's
  - 92% Hydrogen, 8% Helium, 0.1% other stuff
    - Very similar to the Sun's composition
    - Not too far from a binary star system
  - Rich chemistry
    - Ammonia, methane, other hydrocarbons, water, phosphine, etc..
- 400 mph winds
- Incredible pressures
- Increasing temperatures with depth

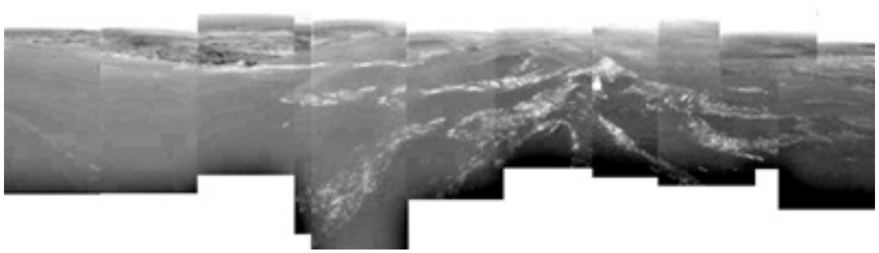
How to search for life?

- How do we search for life in our Solar System and beyond?
- What test will indicate life exclusively?
- Remember the Viking problems on Mars.
  - Need flexibility to test interpretations.
- But, it is difficult to anticipate fully the planet conditions.



How to search for life?

- Is is apparent that future missions need to land as near as possible to sites of subsurface water or other solvents.
- On Titan, what are the important tests for determining biological signatures of non-water life?
- What if the life is still in the protolife stage? Can we detect that?
- The boundary between chemical and biological processes is difficult to distinguish.



Decision Trees– Search for Life

- Wait for it to come to us via meteorites or comets.
- Robotic one-way investigations– Mars rovers.
- Fetch and return with samples.

http://www.ibiblio.org/wm/paint/auth/friedrich/tree.jpg

Problems

- In the last 2 cases, we have the problem of contamination by Earth life.
- Organisms can live in Mars-like conditions on Earth.
- If some Earth life survives the space journey, it could colonize Mars, possibly destroy any Martian life. Think of Kudzu.
- Current missions must be sterilized.

http://www.hope.edu/academic/biology/faculty/evans/images/Angiosperms/CoreEudicots/EurosidsI/Fabaceae/Kudzu.JPG

Biomarkers: How to look for extrasolar life.

- We need to decide how to search for biomarkers or chemical signatures of life.
- On Earth, methane and oxygen are indicators. They normally react. Something is keeping it out of equilibrium. Sort of like Venus disequilibrium.
- The Galileo spacecraft on its way out to Jupiter, turned and looked at the Earth.
- Did it detect life?

Biomarkers: Looking at Earth.

- Strong "red edge" from reflected light. Absorption from photosynthesis.
- Strong O_2. Keeping oxygen rich atmosphere requires some process. It should slowly combine with rocks.
- Strong methane. Should oxidize. Replenished by life.
- Strange radio emissions that could be intelligent life.

http://epod.usra.edu/archive/epodviewer.php3?oid=56256

Biomarkers: Looking at Earth.

- Recently, researchers have looked at the Earthshine from the moon.
- They agree with Galileo result. There is life on Earth.
  - Water
  - Oxygen
  - Tentative detection of "red edge"

http://epod.usra.edu/archive/epodviewer.php3?oid=56256