Lecture 18

# The Origin of Life on Earth

Astronomy 141 – Autumn 2012

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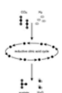
This lecture explores our current ideas about the origins of life on Earth.

How did the raw organic materials (especially amino acids) emerge on the early Earth?

The *RNA World* model proposes that reproduction via RNA emerged first.



"*Metabolism First*" proposes that catalytic networks for processing energy arose first.

*Exogenesis* and *Panspermia* propose that life originated extraterrestrially and migrated to Earth.

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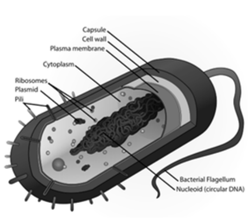
We do not expect the first life on Earth to be as complex as even present-day bacteria.

DNA encoding heredity and cell function.

Catalytic ATP cycle powering cell metabolism.

RNA-mediated protein synthesis

Enzyme-catalyzed cell chemistry




Lipid cell membranes studded with functional proteins

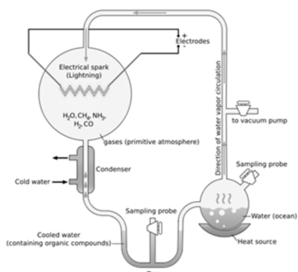
*Product of billions of years of evolution…*

The problem of how life arose from non-life is called *Abiogenesis*.

Basic Requirements:

- Raw Materials:
  - liquid $H_2O$, $CO_2$, organics, phosphates
- Energy Source:
  - Sunlight or inorganic oxidation
- Boundary to contain and organize the components
- Mechanism for catalytic energy utilization ("metabolism")
- Mechanism for Reproduction and Heredity

The Miller-Urey experiment in 1952 showed how amino acids could be made on the early Earth.



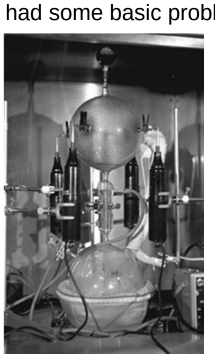

Mixture of $H_2O$, methane ammonia, $H_2$, and CO to simulate the atmosphere.

Electric discharges to simulate lightning.

Precipitated water as "rain" and collected in warm liquid water "ocean".

Quickly built up a murky brown soup of simple amino acids and tars.

The Miller-Urey Experiment was interesting, but it had some basic problems.



Methane & Ammonia were *not* common in the primordial atmosphere

If you use $CO_2$ and $N_2$ you get nitrates that destroy amino acids…

The organics that precipitated out contained only 5 amino acids.

Made both left- and right-handed amino acids in equal proportions.

Recent re-analysis of a second experiment using a volcanic mixture of gases was more interesting.

Electric discharges into a mix of volcanic gases ($H_2O$, $CO_2$, $H_2S$, etc.)

Made 22 amino acids and many other organics.

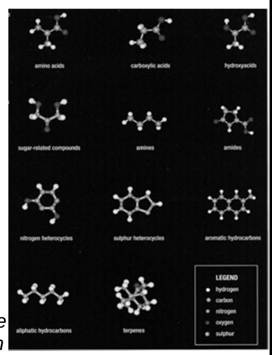
Better match to conditions on the early Earth.

Chaiten Volcano, Chile, May 2008

Complex organics & amino acids are found in some carbon-rich meteorites.

Isotope ratios show a clearly extraterrestrial origin.

Murchison Meteorite




*The key organic compounds were present in the early Solar System*

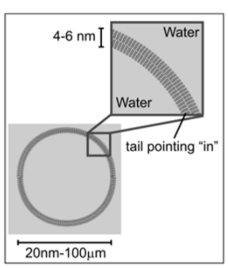
*Lipid Vesicles* are a natural and simple precursor for cell membranes.

Spherical lipid membranes self-assemble spontaneously in liquid water (like soap bubbles).

Grow by absorbing lipids or lipid spheres (micelles).

Split into two vesicles if they grow large enough.

*Perfect containers for proto-life.*



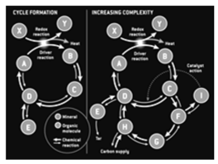

Lipid Vesicle

Raw materials and containers, however, do not automatically lead to life.

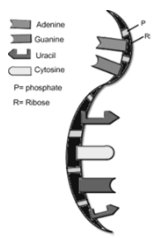
Two scenarios have been proposed for how non-living organics became living organisms:


RNA World – abiotic RNA are the precursors of life

Metabolism First – catalytic networks for processing energy are the precursors of life.



The *RNA World* model proposes that RNA-based life (or proto-life) arose first.




RNA has useful properties:
- Stores information (simple heredity)
- Catalyzes its own replication
- Can act like an enzyme to catalyze reactions ("ribozymes")

Problem is how to make RNA pre-biotically.

- Simple nucleotides form in water in presence of phosphates
- Clays might provide substrates to help nucleotides polymerize into short chains.

A free-floating short strand of RNA gets enclosed in a lipid vesicle to make a kind of "proto-cell".

RNA in its protected vesicle can self-duplicate from other nucleotides.

Easiest to form a double strand when cold.

Double strand RNA unwinds when warmed.

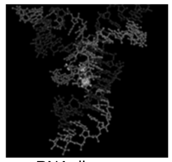
External warm/cold cycles could drive reproduction.

*When vesicle grows & splits, each part carries different bits.*

Evolution acts upon the proto-cells as energetically more efficient reproduction paths emerge.

RNA strand folds up into a ribozyme

- Ribozymes can catalyze replication
- Can also catalyze simple metabolism


RNA ribozyme

Add amino acids…

- Ribozymes help catalyze protein formation
- Proteins fold into enzymes that are much more efficient as catalysts for replication and metabolism.

*Proteins soon take over cell function…*

Final step is the emergence of DNA as the agency of information storage and transmission.

Proteins can catalyze formation of DNA.

DNA is much more stable than RNA and can form long double-helix chains.

More efficient and error-free replicator than RNA.

RNA takes on a subsidiary role between DNA and protein synthesis

*DNA World: the first true prokaryotes.*

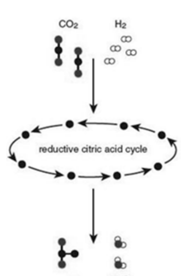
*Metabolism First* proposes that catalytic networks for processing energy are the precursors of life.

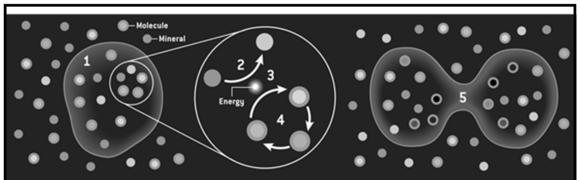
Objection to problem of how complex RNA molecules form abiotically.

Alternative: start with catalytic chemical networks that can process carbon ($CO_2$)

Oxidation of inorganics is most the likely energy source.

Contain them within a lipid vesicle.






[Robert Shapiro, NYU]

1) Lipid vesicle boundary to contain the components

2) Energy Source (oxidation of inorganic minerals)

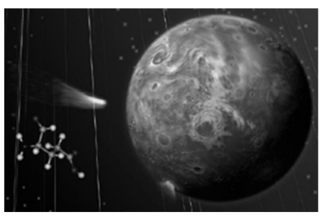
3) Couple of energy release to a “Driver Reaction”

4) Net gain of material by the catalytic network

5) Reproduction of compartments when the vesicles split

*No informational genome or heredity – yet – just “bags of stuff”*

Another idea is that life arose elsewhere in the Universe and migrated here.



*Exogenesis*:
Life arose elsewhere, brought here by comets or asteroids.

*Panspermia*:
“Seed of Life” are widespread through the Universe, and seeded life on Earth.

Neither idea has much support, nor does it address the real problem of how life arises from non-life.