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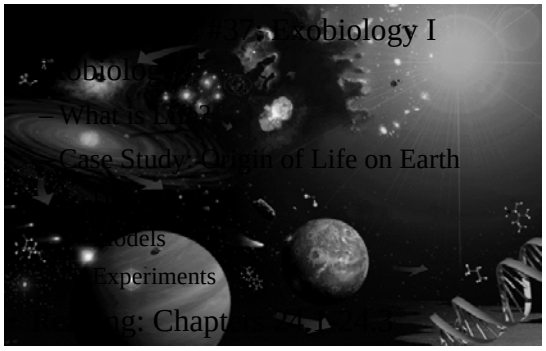

xobiology I

obiology

– What is Life?

Case Study: Origin of Life on Earth

odels

Experiments

g: Chapt

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The Main Point(s)

Exobiology, also called *astrobiology*, is the study of the origin, distribution, and ultimate fate of life in the Universe .

There are several other places in our own solar system besides the Earth where it is reasonable to search for evidence of life

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Astrobiology

- Astrobiology (or Exobiology) is the study of life in the Universe
  - Origin of Life
  - Distribution of Life
  - Ultimate Fate of Life
- Astrobiology today is an *extrapolation* from the one known example (Earth life), using the basic principles of chemistry & physics

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What is Life?

- The question is philosophical, poetic, spiritual, intangible...but also scientific
- To find life we must define what we seek
- "Intuitive" definition:
  - I know it when I see it
  - But not very rigorous
  - Applies only to Earth life?

What is Life?

- A more rigorous definition:
  - Something is alive if it has the ability to ingest nutrients, give off waste products, & reproduce
  - But what are nutrients?
  - What are waste products?
  - What is growth? (mountains "grow")
- Definition must acknowledge that life is hard to define and that there are likely to be exceptions to any rules proposed

Attributes of Living Systems

- Rather than *defining* life, can we *describe* it in terms of specific attributes?
- Life has at least two unique attributes:
  (1) A living system must be able to reproduce, to mutate, and to reproduce its mutations
  (2) A living system must be able to convert external energy sources into useable internal energy sources

But even this gets dicey...

- There are systems with one attribute but not both
  - Chemical Reactions
    - CO_2 "reproduces"
    - But it's not alive!

    CO_2 + sunlight --> CO + O
    H_2O + sunlight --> H + OH
    CO_2 + OH --> CO_2 + H
  - Crystals
    - "reproduce" in regular patterns, get distorted (mutated)
  - Fire
    - Uses "nutrients", converts energy, "grows", "reproduces", ...
  - Many other "fuzzy" cases...
    - Mules? A virus? Computer programs?

The Essential Requirements

- *Liquid Water*
  - "Medium" for the chemistry of life (mobility, nutrients)
  - Stable over wide range of temperatures
  - Unique freezing properties help maintain stability
  - Complex organic compounds don't dissolve in water!
- *Source of Excess Energy*
  - Sunlight (photosynthesis)
  - Chemical (oxidation)
- *Source of Organic Molecules*
  - C, H, N, O, P, S combined in both simple and complex ways
  - "Simple" organic molecules appear to be abundant out there…

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Origin of Life on Earth

- Key Questions:

  (1) Did life originate on Earth or in space?

  (2) If life originated on Earth:

  (a) What were the conditions like on early Earth that made possible the origin of life?

  (b) Did life originate on or near the surface, below the surface, or in the oceans?

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"Panspermia"

- Swedish chemist Svante Arrhenius proposed in 1908 that life is ubiquitous in the Cosmos and that "spores" or the seeds of life were delivered to Earth essentially by accident
  - No attempt to explain how life originated, only how it got to Earth
  - How did the "spores" get off other planets? (impacts?)
  - How did the "spores" survive harsh interstellar radiation?

- More recent variation: "intentional" panspermia
  - Life was planted on Earth by space travelers
  - Popular among science fiction fans and conspiracy groupies
  - Still doesn't explain how life originated though...

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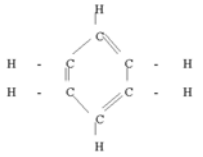
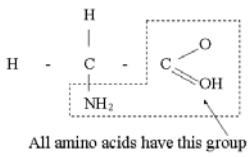
Organic molecules in meteorites

- Some complex organic molecules (molecules containing carbon) have been found in some of the most primitive carbonaceous chondrite meteorites
  - Alkanes, benzene, paraffins, amino acids, …

e.g., Benzene: C_6H_6



e.g., Glycine: $C_2NH_5O_2$



All amino acids have this group

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Organic molecules in exotic places

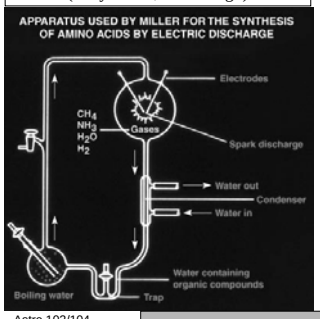
- Complex organic molecules have also been found or inferred to exist in:
  - Interstellar molecular clouds
  - Comets
  - Interplanetary dust particles
  - Some dark asteroids, rings, & planetary satellites
  - Some other "anomalous" meteorites (*e.g.*, ALH84001)

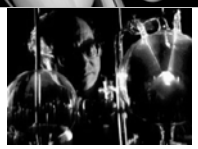
- Did life on Earth originate from raw materials brought in by the early "rain" of debris from asteroid, comet, and cosmic dust impacts?

Could life have originated on Earth itself?

- Recall the hypothesized environment of the early Earth (Lecture 12):
  - Heating of interior, release of volatiles
    - H_2, H_2O, CH_4, and NH_3
  - H_2O forms liquid ocean at Earth's P,T
    - NH_3 dissolves in water
  - Result is a highly-reducing atmosphere
    - H_2, CH_4 abundant
    - Little if any free O_2
- Can *simulate* this environment in the lab...

The Miller-Urey Experiments
(early 1950s, U. Chicago)





- Water = primitive ocean
- CH_4, NH_3, H_2 = primitive atmosphere
- electrical discharge = lightning
- cycling through ocean...

- RESULTS:
  - complex organic molecules
  - simple amino acids!
  - life's building blocks!

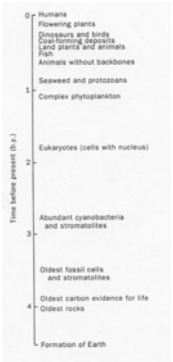
Making Primordial Soup

Life on Earth

- The Miller-Urey experiments were perhaps too simplistic, but they demonstrated that the interactions of liquid water, natural energy sources, and organic molecules leads to the production of complex organic molecules
- Even if the Urey/Miller process was not efficient enough to produce large quantities of organics, remember that organics formed elsewhere were still being delivered to the early Earth by impacts...
- The building blocks of life are abundant in the Cosmos!
- But how did the building blocks become *alive* ???

Life on Earth

- Very soon after the early Earth cooled and the impact rate slowed, life appeared
- How? No one knows...
- Miller-Urey and nearly 50 years of subsequent experiments have not been able to produce this result
- Life has slowly increased the amount of free O_2 in Earth's atmosphere over time
- Atmosphere is in *disequilibrium*



Jakosky (1998)

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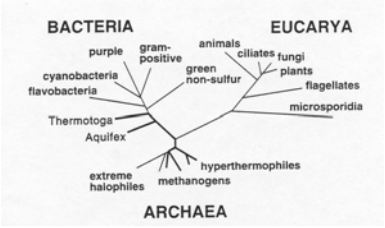
Starting Simple...

- Life on Earth started simple
- Most life on Earth *remains* simple
- All life on Earth is similar at a basic level



"Tree of Life" for Earth, based on similarity in RNA sequences among all life forms (past and present) on this planet

(Woese, 1987)

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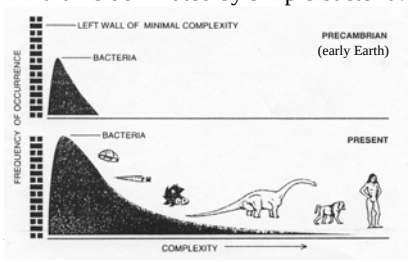
Complexity is rare...

- A census of life on Earth today or 3 billion years ago would reach the same conclusion: life on Earth is dominated by simple bacteria!



Gould (1994)

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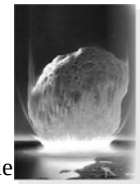
And accidents happen...



- Evolution towards more complex life forms is not necessarily inevitable
  - bacteria are very efficient life forms...
- External, even random forces play a role
  - *e.g.*, Gould's theory of "punctuated equilibrium"
- Starting over again with the same initial conditions, could the experiment be repeated?
  - Would life form at all? (hmm...)
  - Would evolution follow the same path? (probably not)

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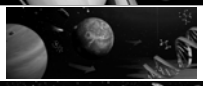
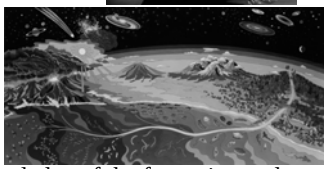
Some Big Questions





- Has this happened elsewhere?
  - in the solar system?
  - in the Galaxy?
  - in the Universe?
- Can we use our knowledge of the formation and evolution of life on Earth to make predictions about the nature, distribution, and abundance of life "out there" ?
- Should we seek simple life, or complex life?

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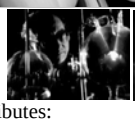
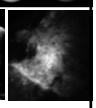
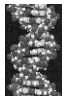
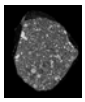
Summary

- Life is a difficult thing to define
- But all life on Earth shares similar attributes:
  - (1) A living system must be able to reproduce, to mutate, and to reproduce its mutations
  - (2) A living system must be able to convert external energy sources into useable internal energy sources
- The raw materials for life are common in the Cosmos
  - Earth may have been "seeded" by early impacts
  - Or a "primordial soup" may have been brewed early
- However it formed, life appeared rapidly on Earth
- Simple life forms dominate life here; complexity is rare...

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- Exobiology II
  - Life in Extreme Environments
  - Searching for Life in Our Solar System
    - More exotic "niches" on Earth
      - Mars
      - Europa
      - Titan? Elsewhere?
- Reading: Continue Chapters 24.1-24.3