

ASTR-1020: Astronomy II
Course Lecture Notes
Section XII

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Abstract

These class notes are designed for use of the instructor and students of the course ASTR-1020: Astronomy II at East Tennessee State University.

XII. Life in the Universe

A. What is Life?

1. Life is matter that can reproduce itself and evolve as survival dictates.
2. Life on Earth is carbon-based. Carbon can easily form long molecule chains.
3. Most life on Earth is composed of **cells** (viruses are not), which have **proteins** as their building blocks. Proteins have **amino acids** as their building blocks.
4. The molecule **DNA** is located in the nuclei of cells. This molecule carries all of the genetic information. It is through this molecule that life is able to reproduce itself.
5. **Evolution** takes place by **mutation** coupled with **natural selection** so lifeforms better adapted to the given environment will survive and reproduce more with these survival traits.
 - a) There various ways mutations can take place. First, changes in DNA can be caused by natural radioactivity from the Earth's surface and/or cosmic rays.
 - b) Modifications of DNA due to reproduction.

B. How Did Life Start?

1. In 1952, the **Miller Experiment** (also referred to as the Miller-Urey or Urey-Miller Experiment) created amino acids from H_2O (water), CH_4 (methane), NH_3 (ammonia), and H_2 (molecules

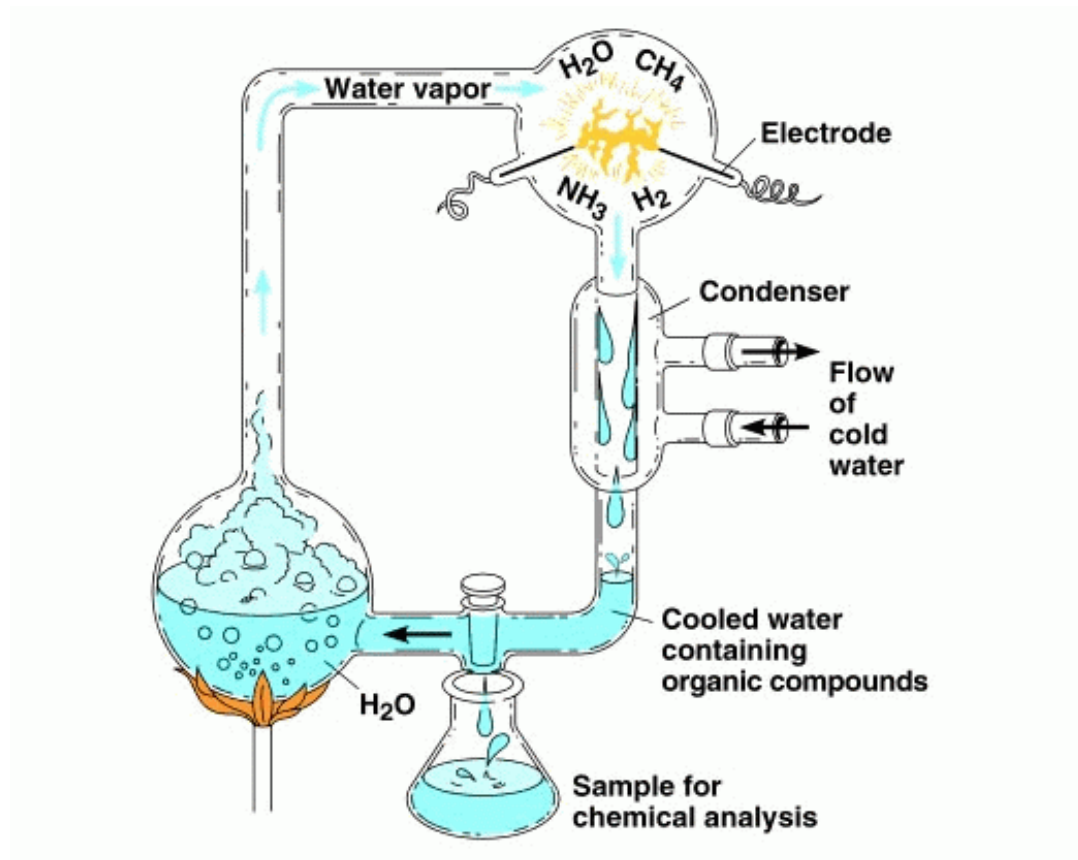


Figure XII-1: Experimental setup by Urey and Miller to simulate the early Earth atmosphere.

common in the early Earth's atmosphere) when an electric arc (to simulate lightning in the early Earth atmosphere) was passed through this mixture (see Figure XII-1 and Figure 28.3 in the text).

- a) A few hours into the experiment, a brownish-orange film formed in the experimental apparatus.
- b) This *film* was analyzed and was found to be amino acids!
- c) The experiment was later repeated with ultraviolet light (to simulate sunlight) instead of an electric arc as the energy source and the same results were obtained.
- d) This experiment showed that nature can make organic compounds out of simple inorganic molecules very easily.

2. Not only are organic compounds easy to make, we see them throughout the Galaxy!
 - a) Nonterrestrial amino acids have been found in meteorites.
 - b) The spectral lines from amino acids and other organic molecules also have been detected in the interstellar medium.
 - c) The spectral lines from organic molecules have been detected in the atmosphere of Saturn's largest moon Titan.
 - d) **The Universe has no trouble creating organic compounds in a very simple and natural manner!**

3. It's a big step however to go from organic molecules to self-replicating organic molecules (*i.e.*, life). Many experiments have been carried out since the Miller-Urey Experiment to try and understand how life got started from this building block material.
 - a) Biologists have been able to grow structures from amino acids that resemble proteins.
 - b) Long carbon-chained molecules are very fragile and are easily broken apart when left by themselves. However, experimentalists have found that long carbon-based molecule chains can form, grow, and survive in mud and clay.
 - c) This may suggest that we may owe our very existence to our large natural satellite — the Moon! The Moon raises tides on the shores of the continents. This moistens the dirt making mud and the organically rich oceans deposit amino acids and other organic molecules in this mud.

- d) As the tides continuously raise and lower, long carbon-based molecules chains began to flourish. As time went on, electrochemical reactions between the chains started to take place forming more complicated molecule chains until one chain was made that was able to make copies of itself — micro-organisms arose and flourished in the oceans as the tides swept this material back out.
 - e) There is no magic going on here, just chemistry being powered by an energy source (*i.e.*, the Sun). Mutations from cosmic rays and the UV radiation from the Sun cause further alterations to these long molecule chains \implies variation in lifeforms begin on Earth. Natural selection begins in earnest causing organisms that are successful in their environment to survive, be fruitful and multiply. And the rest is history!
4. There is also some thought in the scientific community that the building blocks of life may have been deposited on Earth from space since amino acids are fairly common in meteorites and the interstellar medium. This hypothesis is referred to as **panspermia**.

C. The Search for Extraterrestrial Life

1. The study of possible life off the Earth (*i.e.*, *extraterrestrials*) is called **exobiology**.
2. The first question to ask is “are there simple lifeforms elsewhere in the Solar System?”
 - a) The best planets (besides Earth) suited for life in the Solar System are Mars, Jupiter’s atmosphere, Europa’s submerged ocean, and Titan (although Titan may be too

cold to support the formation of long molecule chains).

- b) Saturn's largest moon Titan:
 - i) The *Voyager* spacecrafts observed organic compounds in Titan's atmosphere.
 - ii) The spacecraft *Cassini*, which is currently in orbit around Saturn, confirmed these observations. *Cassini* launch a probe called *Huygens* which landed on Titan's surface in January 2005.
 - iii) During the primary mission *Cassini* investigated the structure and complex organic chemistry of Titan's thick, smog-filled atmosphere. On the frigid, alien surface, the spacecraft and its *Huygens* probe revealed vast methane lakes and widespread stretches of wind-driven hydrocarbon sand dunes. *Cassini* researchers also deduced the presence of an internal, liquid water-ammonia ocean.
- c) *Vikings 1* and *2* looked for life on the surface of Mars with negative results.
 - i) Images from the *Viking* orbiters and the recent Mars mapping missions have shown that liquid water did exist on the planet's surface early in its history.
 - ii) Indeed, recent evidence gathered by the *Mars Global Surveyor* suggest that Mars may still have a substantial amount of water ice in some areas less than 500 meters (1640 feet) below the surface.

- iii) Did life have time to get started there before the liquid water evaporated from Mars' surface?
 - iv) A meteorite found in Antarctica was identified as originating from Mars a few years ago. Small nanometer sized *wormlike* structures were found inside this meteorite and NASA scientists speculated that it represented ancient Martian life. Continuing analysis of this meteorite now shows doubt that these structures are due to life, but instead, due to inorganic chemistry. The debate is still continuing.
 - v) Two rovers are currently on Mars and a fleet of spacecraft have been orbiting this planet over the past decade. Though these spacecrafts have not detected life, they have discovered evidence that Mars once had liquid water on its surface. As such, it is possible that Mars once may have supported simple lifeforms in the past.
 - vi) If Mars did have microbial life early on, it is doubtful that this life is still present in the Martian soil today.
- d) Observations from the *Voyagers* and the *Galileo* spacecraft have shown that Jupiter's moon Europa has cracked water ice on its surface which suggests a liquid subterranean ocean beneath the ice crust. As the moon orbits Jupiter, it is tidally pulled in and out which heats the interior of the moon.

- i) This may cause volcanism on the floor of Europa's ocean. On the Earth, such ocean-bottom *lava vents* are home to many organisms.
 - ii) As a result, Europa's ocean may be teeming with life.
 - iii) NASA has started work on developing a spacecraft that will go to Europa within the next 20 years. This spacecraft will launch a *penetrator* into Europa's ice crust to gain access to the ocean below and conduct studies on possible lifeforms there.
3. There are no other technological civilizations in the Solar System. The search for extraterrestrial technological civilizations must look beyond the Solar System. This search has been designated **SETI**: the Search for ExtraTerrestrial Intelligence.
- a) A technological civilization is defined to be one that has developed **radio astronomy** — we have only been a technological civilization for 60 years!
 - b) The number of technological civilizations in the Galaxy can be estimated by **Drake's Equation**:

$$N_c = N_\star f_p n_{\ell z} f_\ell f_I F_s. \quad (\text{XII-1})$$

- i) N_c = number of communicative (*i.e.*, technological) civilizations in the Galaxy.
- ii) N_\star = number of stars in the Galaxy:
— we know this accurately: 2×10^{11} stars.

- iii) f_p = fraction of stars with planets:
- new planetary systems are being discovered every year in the solar neighborhood.
 - space observations over the past 20 years have discovered numerous of planetary systems forming around stars in stellar nurseries.
 - stellar formation modeling give this fraction a value anywhere from 1/2 to 1!
 - to be conservative, let's choose 1/2 for this fraction.
 - $N_p = N_\star f_p = 1 \times 10^{11}$ planetary systems.
- iv) $n_{\ell z}$ = number of planets per star that lie in the **habitable zone** for at least 4 billion years:
- a habitable zone is a region around a star where a planet can have temperatures that permit the existence of liquid water \implies F5 V – K5 V stars.
 - models predict this number to range between 0.01 and 1 per star.
 - 4 billion years chosen here due to length of time it took intelligent life to evolve on Earth.
 - $N_{\ell z} = N_\star f_p n_{\ell z} = 10^9 - 10^{11}$ habitable zone planets.

v) f_ℓ = fraction of suitable planets on which life begins:

- we can only guess at this number.
- organic chemistry and the Miller Experiment suggests the answer is 1.
- we perhaps need to include the fraction of those planets that possess a large natural satellite at this point in order for stable long molecule chains to form.
- we will assume that this fraction ranges from 0.01 to 1.
- $N_\ell = N_\star f_p n_{\ell z} f_\ell = 10^7 - 10^{11}$ planets with life.

vi) f_I = fraction of lifeforms that evolve to intelligence and develops radio astronomy:

- we can only guess at this number too.
- 0.01? – 1?
- $N_I = N_\star f_p n_{\ell z} f_\ell f_I = 10^5 - 10^{11}$ planets with intelligent life.

vii) F_s = fraction of star's life during which a technological society survives:

- completely unknown, destruction by nuclear war, overpopulation, pollution, mass extinctions from asteroid impacts.
- if 100 years: $F_s = 10^{-8}$.
- if 1,000,000 years: $F_s = 10^{-4}$.
- $N_c = 10^{-3} - 10^7$ technological civilizations in the Milky Way.

- c) If $N_c \leq 1$, we are the only technological civilization in the Galaxy.
- d) If $N_c \gg 1$, technological civilizations are everywhere in the Galaxy.
 - i) If $N_c = 10^7$ civilizations, the average separation of each system is 120 ly.
 - ii) If this many exist, there should be many civilizations more advanced than us \implies where are they?
 - UFO's not the answer! No scientific evidence that these *events* are extraterrestrial in origin.
 - Also, travel time is too long (can't go faster than light) and it would be very expensive from a raw materials point of view.
 - iii) Von Neumann Machines (machines that travel to the next nearest star and reproduce themselves, sending their offspring to the next nearest stars, etc.) should be seeding the Galaxy by now \implies where are they?
 - iv) Maybe we are the first to achieve technology! (Somebody has to be first.)
- e) We the listeners: radio astronomy.
 - i) Technological civilizations = ones that have radio telescopes.
 - ii) The laws of chemistry and physics are universal \implies water (H_2O) should be an important to all lifeforms. As such, ET might broadcast between

the H (*i.e.*, 21 cm) and OH (*i.e.*, 18 cm) lines \implies the **water hole**. There is little galactic noise in this part of the radio spectrum, hence a good place to send signals (see Figure 28.17).

- iii) Nothing found yet. The Horowitz experiment is now looking using a billion channel receiver (Project BETA). A few signals have been detected, but nothing has repeated. A detection cannot be confirmed unless it repeats and is verified by other scientists.

- iv) If a signal is ever found, will it cause culture shock? (Personally, I don't think that is likely.)

- f) We the talkers:
 - i) Radio astronomy: we have sent messages. Dr. Frank Drake sent a binary signal with a variety of useful information off towards the globular star cluster M 13 in the 1960's. Unfortunately, the signal will not get to this cluster for another 30,000 years!

 - ii) Spacecraft emissaries: *say it better with Voyagers*:
 - Pioneers 11 & 12 have gold plaques onboard with drawings of humans, our Solar System, and our location in the Galaxy with respect to neutron stars.

- Voyagers 1 & 2 each have a video disk and player onboard — the disk contains pictures of our society and the Solar System. As well, it contains verbal greetings from all languages and songs including Chuck Berry’s *Johnny Be Good!*
4. We are closer to answering this question of *whether or not we are alone in the Universe* than we ever have been throughout history. Humans seem to fear loneliness, so this question is very important to many people. Hopefully, with the aid of our current technology, we will discover the evidence of extraterrestrials in our lifetime.
 5. Once they are found, it will be a “Herculean” effort to try to decode any signal that comes our way from another intelligence. It should be doable, however, since all technological civilizations will have one language in common — the language of **mathematics!** \implies The Universe behaves in a logical fashion, described by the laws of physics written in the language of mathematics. Let the search continue ...