Lab 6: Astrobiology

"Sometimes I think we're alone in the universe, and sometimes I think we're not. In either case, the idea is quite staggering."

— Arthur C. Clarke

1 Introduction

Today we will be talking about *astrobiology*, the study of life outside Earth. While this may sound like the stuff of science fiction, we will use actual science (and some simple math) to explore the possibility of extraterrestrial life. Physical experiments are crucial for scientific progress, but these kinds of thought experiments often serve as vital tools to advance our understanding of nature. Most of these questions do not have one correct answer, so it is important to validate and explain your thinking. **The explanation you provide for your answer is far more important than the answer itself.** Before you begin the lab, write down a guess for if/when we will discover life elsewhere in the universe.

2 What is Life?

First, discuss these questions with your partner/group and write down your thoughts in your class notebook. We will examine them together afterwards.

1. How would you define "life"? How can you distinguish living things from non-living things?
2. What is *intelligent* life? How would you distinguish intelligent life from non-intelligent life? Are humans intelligent? Are chimpanzees? What are some examples of intelligent and non-intelligent life?
3. What does life need in order to survive? Think about the basic necessities of humans and other living things.
4. What are some of the ways in which a species can become extinct? Are some of those outcomes preventable by sufficiently "advanced" civilizations? Are some outcomes *unique* to such civilizations? Give examples.

5. Make an educated guess for the typical lifetime of an intelligent civilization based on the following table and explain why/how you came to that conclusion.

Age of the universe	$\sim$ 13,700,000,000 years
Age of the Earth	4,600,000,000 years
Earliest evidence of fossil bacteria	3,500,000,000 years ago
First multicellular fossils	1,500,000,000 years ago
Earliest invertebrates	800,000,000 years ago
Fish & amphibian domination	590,000,000 - 248,000,000 years ago
Mammals dominant	since 65,000,000 years ago
Homo sapiens	originated $\sim$ 300,000 years ago
Human civilization	$\sim$ 10,000 years old
Radio communication	$\sim$ 125 years old
Earth becomes hostile to human life	100 - 100,000,000 years into the future

3 The Habitable Zone

The habitable zone, also known as the 'Goldilocks Zone', is the distance from a star at which liquid water can exist on a planet orbiting that star. It is called the habitable zone because we assume that (most) life forms require liquid water in order to survive.

1. Within what temperature range, in degrees Celsius and on the Kelvin scale, is water in liquid form? Recall that the temperature in Kelvin is the temperature in Celsius degrees plus 273.

2. Below is an equation which relates the distance between a planet and its "host" star, d, and the **average** temperature on the surface of the planet, T. Note that this temperature also depends on the luminosity L, or energy output rate, of the host star, since that is usually the source of a planet's heat.

$$T = \left(\frac{L}{16\pi\sigma d^2}\right)^{1/4}$$

Use this equation to find the minimum and maximum distance from the Sun at which water will be in liquid form. The luminosity of the Sun $L_\odot = 3.8 \times 10^{33}$ erg/s, and $\sigma = 5.7 \times 10^{-5}$ erg/s/cm^2/K^4. Note that T is in units of Kelvin.

3. The current distance between Earth and the Sun is 1.5×10^{11} m (1 AU). Calculate what the average surface temperature of the Earth should be based on that distance. (Mind your units!!!)

4. The actual average temperature at the surface of the Earth is 15° C. How do your results compare to the actual value? If they are different, explain why that might be the case.

4 The Search for Life on Other Planets

The SETI (Search for Extraterrestrial Intelligence) Institute is constantly monitoring stars in our Galaxy for signals from intelligent life on other planets. It is thought that the signals might be in the form of radio waves. Radio waves, like all other light, are a type of electromagnetic radiation. All electromagnetic radiation travels at the speed of light, $c = 3.0 \times 10^8$ m/s[1].

A light year is a unit of distance (not time!): rather unsurprisingly, it is the distance light travels in one year. Besides the Sun, the closest star to us (Alpha Centauri) is 4.3 light years away. The radius of our Galaxy is approximately 50,000 light years.

1. How long would it take for a light signal from Alpha Centauri to reach us? How long would it take for a light signal from 50,000 light years away to reach us?

2. If we learn tomorrow that SETI has detected radio signals from a star-planet system 50,000 light years away, would you think the civilization responsible for the signal is more or less advanced than ours? Why?

5 The Drake Equation

Astronomer Frank Drake created the following equation to determine the number of intelligent alien civilizations N that are able to communicate with us:

$$N = R_* \times f_p \times n_e \times f_L \times f_I \times f_C \times L.$$

[1] c is the speed of light in a vacuum; light travels more slowly through dense media. For the purposes of this lab (and often, for astronomical purposes), you may assume that light travels at the same speed everywhere in the universe.

R_* is the rate of star formation in our Galaxy.
f_p is the fraction of stars that host planets.
n_e is the average number of habitable planets for every star that has planets.
f_L is the fraction of habitable planets that actually develop life.
f_I is the fraction of life-inhabited planets that develop intelligent life (civilizations).
f_C is the fraction of civilizations that develop technology that releases detectable signs of their existence into space.
L is the expected lifetime of such a civilization.

1. What units does N have?

2. R_* is about 10 stars per year. Make educated guesses for the values of the other parameters. *Explain your reasoning in each case.*

3. What do you get for N? How does it compare to the observed value of N?

4. In what ways is Drake's equation useful? In what ways it is not useful? Is it scientific? What might be missing from Drake's equation? Your answer should refer back to other sections in today's lab.

6 Conclusions

1. Think back to the Earth-Moon-Sun lab. How do the Earth's seasons affect its habitability? What about its eccentricity? What would life on a comet (very eccentric orbit) be like?

2. Extremophiles are organisms on Earth that live in extreme conditions, such as the depths of the ocean where no light can penetrate or extremely hot volcanic vents. What does their existence on earth suggest about life on other planets? Comment on this in light of the quote at the beginning of the lab.

3. The Mars Reconnaissance Orbiter confirmed that liquid water currently flows on the surface of Mars. What does this tell us about the possibility of life on Mars?

4. Europa is one of Jupiter's moons. The interior of Europa is rocky, like the Earth. Beyond this rocky interior is an outer layer of water that is about 100 km thick. The water layer is composed of an icy crust, underneath which is presumably a liquid ocean. What does this tell us about the possibility of life on Europa?

5. As the Sun ages and becomes a red giant star, it will expand outward, its surface eventually extending out as far as Earth's orbit (enveloping Earth!). Let's think about what happens before then. How will the surface temperature of Earth change when the distance between the Earth and the Sun is half of what it is now? Be quantitative.

6. Most stars in our Galaxy are less massive than the Sun, meaning they are smaller and output energy at a lower rate. Based on this fact, would you expect typical planets that harbor life to be closer to or further from their host star than the Earth is to the Sun?

7. Finally, look back at your prediction from the introduction. Have you changed your mind? Why or why not?

8. What did you like or dislike about this lab? Did anything confuse you?