Lab 8: 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 of Earth. While this may sound like the stuff of science fiction, we'll try to use actual science (and some simple math) to explore the possibility of extraterrestrial life. While physical experiments are crucial for scientific progress, these kinds of thought experiments often make vital tools in advancing 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 with your answer is more important than the answer itself. Before you begin the lab, write down a guess for when (or even if?) we will find life elsewhere.

2 What is Life?

First, talk to your partner/group about these questions and write down your thoughts. We will discuss them as a class afterwards.

1. How would/could/should you define life? How can you distinguish living things from non-living things?
2. What is intelligent life? How can you distinguish intelligent life from non-intelligent life? Give an example of an intelligent life-form and a non-intelligent life-form.
3. What does life need 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? Name at least three of those ways. Are some of these fates preventable by sufficiently "advanced" civilizations? Are some fates unique to them? Make an educated guess for a typical lifetime of an intelligent civilization based on the following table and explain why.

Age of the universe	$\sim$ 13,700,000,000 years
Age of the Earth	4,600,000,000 years
Earliest fossil 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 250,000 years ago
Human civilization	$\sim$ 10,000 years old
Radio communication	$\lesssim$ 100 years old

3 The Habitable Zone

The habitable 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 requires liquid water to survive.

1. Between what temperatures, in degrees Celsius and on the Kelvin scale, is water liquid? 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 star, d, and the average surface temperature on the planet, T. Note that it also depends on the luminosity $L_\odot$, or energy output, of the star since that is where planets get their heat.

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

   Use the equation to find the minimum and maximum distance from the Sun at which water will be liquid. Note: $\mathrm{L}_\odot = 3.8 \times 10^{33}$ ergs/second, $\sigma = 5.7 \times 10^{-5}$ erg/s/cm^2/K^4. T must be in Kelvin. The distance you calculate with this equation will be in cm.

3. The current distance between the 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.

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.

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 would be in the form of radio waves. Radio waves are a type of electromagnetic radiation, as is all other light. All electromagnetic radiation travels at the speed of light, $c = 3.0 \times 10^8$ m/s.

A light-year is a unit of distance: 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 51,000 light-years.

1. How long would it take for a signal from Alpha Centauri to reach us? How long would it take for a signal from 51,000 light-years away to reach us?

2. If we learn tomorrow that SETI has detected signals from a star-planet system 51,000 light-years away, do you think the civilization responsible for the signal is more or less advanced than ours? Why?

3. Speculate on the feasibility of having a "conversation" with an alien civilization.

5 Drake's Equation

Astronomer Frank Drake created the following equation to determine the number of intelligent civilizations that are willing and able to communicate:

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

R_* is the rate of star formation in our galaxy.
f_p is the fraction of stars that have 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 the above with intelligent life.
f_C is the fraction of the above that develop technology that releases detectable signs of their existence into space.
L is the expected lifetime of such a civilization.

1. What does N represent? Show that it has proper units by writing the equation out explicitly with the units of all the variables.

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 cold climates. 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. As the Sun ages and becomes a red giant star, it will expand outward, eventually going all the way to Mars (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.

4. Most stars in the galaxy are less massive than the Sun, meaning they are smaller and do not output as much energy. Based on this fact, would you expect planets that harbor life to be closer to or further from their host star than the Earth is to the Sun.

5. Finally, look back at your prediction from the introduction. Do you still think that? Why or why not?

6. If the lab was perfectly clear to you, what did you like or dislike? If not, what confused you? As usual, ask a question.