Astronomy 1010 Lab – **Life in the Universe** – V2.0

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Learning Objectives:

▶ **Science Processing Skills**: Interpreting data along with applying and evaluating mathematical relationships.

→Understanding the habitable zone.

→Understanding that the habitable zone is not all-encompassing.

→Using and modifying a formula, namely the Drake Equation.

→How all of the points above tie together in the search for life.

Introduction: *In space there are countless constellations, suns and planets; we see only the suns because they give light; the planets remain invisible, for they are small and dark. There are also numberless earths circling around their suns, no worse and no less than this globe of ours.*
– From *De l'Infinito Universo e Mondi*, by Giordano Bruno, 1584.

Pre-Lab Exercises

Take a few minutes to answer the questions below thoughtfully (not simply yes/no). Integrate as much material from class as you can when answering and justify your responses.

1) In your own words, what is life?

Life can mean many things but for thsi context, it is thought and a host.

2) Do you believe there is life outside of Earth?
What about "intelligent life"?

I think that " life " exists outside of Earth, just not in the way we ' re expecting it to be. It ' s a little hard to believe that humans are the only " intelligent life " in the galaxy. If there ' s anything that this class has taught me, it ' s that out universe is much larger than we can imagine. Statistically, there are chances that there are other " life " out there.

3) Do you believe there is life beyond Earth but within our Solar System?

No, but I ' m keeping an open mind. Scientists have been doing research for ages and we would at least have a small amount of proof of other life by now. There is a chance that there really is life beyond Earth, maybe we need more time and resources.

What Life Needs

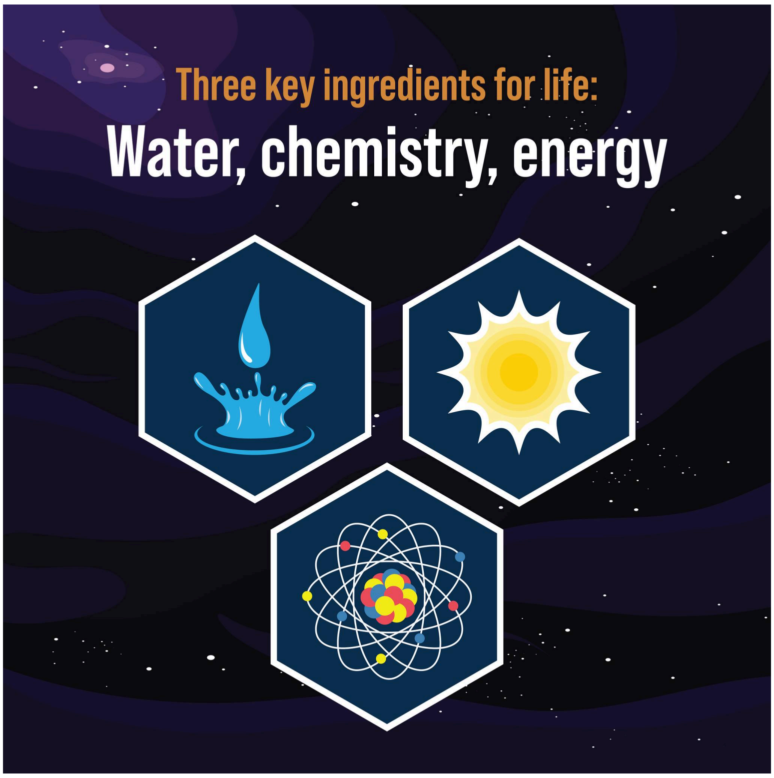

Image Credit: LabXchange, public domain

Water: All life as we know it requires liquid water. Water helps cells maintain their shape while facilitating the biochemical processes within cells. Water also transports nutrients and waste products.

Chemistry: Carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur are often called "the building blocks of life". These elements alone make up 98% of all living matter on Earth. These elements form simple as well as complex organic molecules, including the carbohydrates, lipids, proteins, and nucleic acids found in your body.

Energy: Energy is a fundamental requirement for life as it powers the processes that allow living organisms to grow, reproduce, respond to their environment, and maintain internal balance. On Earth, most of the energy that powers living creatures originates from the Sun.

In order for liquid water to exist on a planet, that planet must not be too close to its star, otherwise the temperatures would be too and the water would completely evaporate. Similarly, if the planet is too far from its star, any water would freeze. The region around a star where liquid water can exist is known as the **habitable zone**, sometimes also referred to as the "Goldilocks zone". Let us explore this concept. Go to this simulator: **Circumstellar Habitable Zone Simulator**

You will notice that by default, the simulator chooses a star of $1M_\odot$ (the mass of the Sun) and a planet that is 1 AU away (the Earth). The bottom grid shows the "time since star system formation", or in other words, the time since the star began hydrogen fusion (main-sequence lifetime). If you click on "run" it will quickly go through over 13 billion years of evolution! The easiest thing to do is to just drag the triangle in the timeline and you can see how the habitable zone changes.

4)At time t = 0 what planet(s) are in the habitable zone? Note that in order to zoom out or in, you can move the slider in the "initial planet distance". So for example if you move it out to 20 AU you will see the inner planets and Jupiter, Saturn, Uranus, and Neptune as well.

At time t = 0, Earth is in the habitable zone.

5)The current age of the Earth is about 4.5 billion years. Move the timeline until the Earth just leaves the habitable zone. In total, how many years will the Earth have been in the habitable zone? Explain why the habitable zone changes with time.

Earth moves out of the habitable zone in 5.45 Gy, 5,450,000,000 years. The habitable zone changes with time because the sun (a star) affects the planets around it with it ' s heat.Over time, this heat changes which in turn affects how the surrounding planets survive—whether the case is water evaporating or temperature dropping below usual.

6)Approximately when does Mars (distance of 1.5 AU from the Sun) enter the habitable zone? For how many years does Mars stay in the habitable zone?

Mars enters the habitable zone 6.20 Gy, 6,200,000,000 years and stays in the habitable zone for 11.0 Gy, 1,100,000,000 years.

7)Now imagine our Sun was 20% more massive than it is. At t = 0 what planet(s) are in the habitable zone, and how long do they stay in the habitable zone?

At inital star mass of 1.2 M, 1 AU, and time t = 0, Mars ’ orbit is in the habitable zone. At inital star mass of 1.2 M, 1.5 AU, and time t = 0, Mars is in the habitable zone. It stays in the habitable zone for 2.8 Gy, 2,800,000,000 years

8)Let us now double the Sun's mass. At t = 0 what planet(s) are in the habitable zone, and how long do they stay in the habitable zone?

At 2M (double the Sun ’ s mass of 1) and time t = 0, Jupiter is in the habitable zone for 1.15 Gy, 1,150,000,000 years with 5.11 inital planet distance.

9)Finally, determine how long Venus would stay in the habitable zone if the Sun's mass was reduce to 70%. Venus is 0.72 AU from the Sun.

Venus would be in the habitable zone at t = 28.9 Gy, 2,890,000,000 years, 0.7M and 0.720 AU. It would stay in the habitable zone ffrom 28.9 Gy to 42.0 Gy, 4,200,000,000 years.

10) Based on your findings, what type of star do you think might be most conducive to life and why?

Stars with a warm but not hot presence on the habitable planet would be most conducive to life because they would have the longest efficiency and provide the best warmth for life.

Energy

The chemical reactions that power life, and power you, all need energy. Nearly all the energy that powers life on Earth originates in the Sun. In general, scientists believe that if a planet is within the habitable zone, there is a good chance it can support life. Naturally, you might assume that if a planet is not in the habitable zone, it can not support life. However, that is not necessarily the case!

Let us consider Venus. As you learned, the temperature on the surface is 738 Kelvin (870 Fahrenheit) which is hotter than an oven. At such temperatures, life as we know it can not exist.

11) While we do not yet know whether life exists on Venus, surprisingly there is evidence to support the hypothesis that life can actually exist on such a planet! The figure below shows the temperature of Venus with respect to height above the surface. At 90 km above the surface (see the right-hand side) the temperature is -100 degrees Celsius. At roughly what height do you think life could potentially exist? Also, why is Venus not taken into account when looking at the habitable zone? In other words, what does the habitable zone calculation *not* take into consideration?

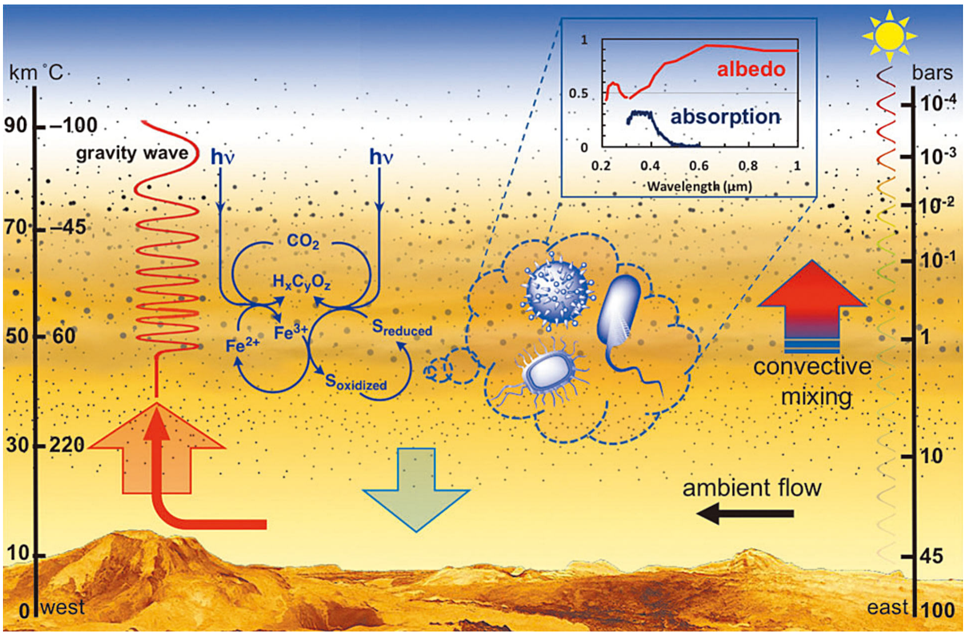

Image Credit: Limaye et al, doi: 10.1089/ast.2017.1783

Since the temperature at 90 km is -100 Celsius is almost impossible, a distance of 50 km and 60 C is more possible with organisms that can survive at that temperature. Venus is not considered when looking at the habitable zone because of how far it it and factors like its ’ air pressure, gravity, temperature, and landscape.

On October 14 (2024), NASA launched the **Europa Clipper** probe, whose mission is to determine "whether there are places below the surface of Jupiter's icy moon, Europa, that could support life." The probe is expected to reach Europa by 2030.

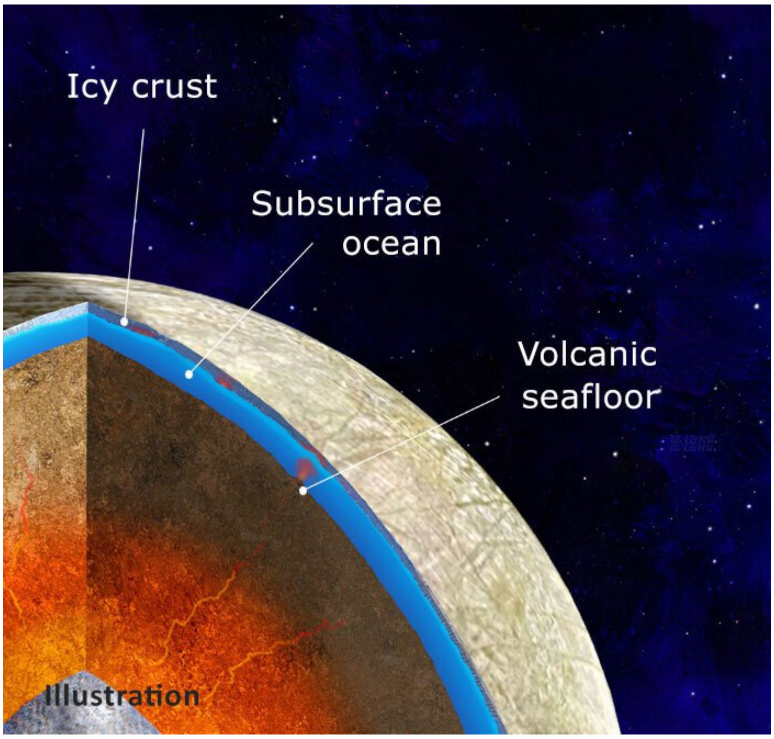

Image Credit: NASA/JPL-Caltech/Michael Carroll

Since liquid water requires energy, where does this energy come from? The answer is tides. Recall that tides are basically the stretching and squeezing of an object due to gravity. Such stretching and squeezing can impart substantial energy and this is known as **tidal heating**. In order for the insides of an object, such as Europa, to experience tidal heating it must:

a)Orbit a comparably massive object.
b)Have a substantial radius.
c)Be on an eccentric orbit.
d)Have a comparably small semimajor axis.

Consider the theoretical moons below. The first column is the "name" of the Moon. The second column is the mass of the planet the moon is orbiting, in Jupiter mass. The third column is the radius of the moon relative to the planet it is orbiting. The fourth column is the eccentricity. And the last column is the semimajor axis in planet diameters.

Name	Mass of Planet (Jupiters)	Radius (relative)	eccentricity	a (planet diameters)
A	0.003	0.25	0.05	30
B	1	0.0256	0.004	3
C	0.052	0.055	0.0002	7

12) Which moons could potentially have a subsurface ocean due to tidal heating? Justify your answer.

Out of all three moons, moon B could potentially have a subsurface ocean due to tidal heating. Tidal heating depends on string tidal forces that can provide heating to maintain the ocean. With moon B ' s low eccentricity of 0.004 and large planet mass of 1, it makes the best moon for having a subsurface ocean compared to A and B.

Drake Equation

We have considered whether there could be life outside of Earth, but still in our Solar System. What about life in the entire universe? In 1961, astronomer Dr. Frank Drake wrote down a simple formula for determining how many “intelligent” civilizations exist in our Milky Way galaxy. Today, the formula is known as the **Drake Equation** –

$$\mathcal{N} = \mathcal{R}_* \times \mathcal{F}_p \times \mathcal{N}_e \times \mathcal{F}_l \times \mathcal{F}_i \times \mathcal{F}_c \times \mathcal{L}$$

N is the number of technologically advanced civilizations.
$\mathbf{R}_*$ is the rate of star formation per year.
$\mathbf{F}_p$ is the fraction of those stars with planets.
$\mathbf{N}_e$ is the number of habitable planets in a solar system.
$\mathbf{F}_l$ is the fraction of habitable planets in which life forms.
$\mathbf{F}_i$ is the fraction of life-bearing planets where intelligent life emerges.
$\mathbf{F}_c$ is the fraction of intelligent civilizations that send detectable signals.
L is the length of time a civilization sends detectable signals.

13) Before we calculate the number of “intelligent civilizations”, let us calculate how prevalent any form of life may be in the universe. To do this, first modify the Drake Equation, and write down this new formula.
To find any form of life, not just intelligent, the equation can be modified to:
R × Fp × Ne × F/ = N (life).

14) Take your best shot! Calculate how prevalent life in general may be by using the formula from the previous question and also what you believe are reasonable values. Note that you are not expected to know these values – use what you have learned from class and estimate what you think are reasonable values for the variables in the equation.
Note: the following values are from Google and this class:
7 × 1 × 0.4 × 0.1 = 0.28

15) Today, we know that the *observable Universe* is not infinite (this theory will be discussed in detail in 1020)! While there are not "numberless earths" we suspect that there are so many planets that they are seemingly *countless*. We have confirmed over 5100 **exoplanets** – planets beyond our Solar System. While this number is small, we have truly only begun searching for them, and we believe there are at least 100 billion planets in our Milky Way. While we currently do not know how many planets may be habitable, many scientists believe the answer might be astoundingly large.

Current estimates are: $\mathbf{R}_* = 1$, $\mathbf{F}_p = 1$, $\mathbf{N}_e = 0.2$, $\mathbf{F}_l = 1$, $\mathbf{F}_i = 1$, and $\mathbf{F}_c = 1$. You will notice that the only value not included and arguably the most "controversial" number is the lifetime of a technologically advanced civilization. The famed astronomer and science communicator, Carl Sagan, noted that an advanced civilization, such as our own, might "extinguish" itself through war. Hence, perhaps **L** is only 10,000 years. However, other scientists believe the value is far larger. Some have argued that **L** is in fact closer to the age a star could sustain life, and this could be 10 billion years (or more)! If we are optimistic, what value do we get for:

a) Life in general (again, use your formula).
b) **N** (plug into the Drake Equation).

a.
N (life) = R × Fp × Ne × F/
N (life) = 1 × 1 × 0.2 × 1 = 0.2
b.
N = R × Fp × Ne × Fl × Fi × Fc × L
N = 1 × 1 × 0.2 × 1 × 1 × 1 × 10000 = 2000

16) Has this lab changed your mind, or reinforced your original belief, regarding life outside of Earth?

This lab as reinforced my original belief, I first learned about the Drake Equation from Young Sheldon. I ’ m excited that I got the chance to learn more about it.

It is always important to be both critical, and open-minded at the same time. Just because we have not found any life outside of Earth, as of yet, certainly does not rule it out. That said, one very enjoyable aspect of all this is imagination – “I wonder what aliens might act and look like?”

17) Describe an alien living on another planet! Explain why the alien is the way it is – for example, perhaps the alien’s planet is orbiting a star much dimmer than the Sun and therefore needs big eyes! Note, if you are able to (this is not required), feel free to sketch the alien and be sure to include it with your lab! Be creative, have fun in your final Astronomy 1010 Lab Question ★

An alien that ’ s not dependent or made with water seems more realistic. Perhaps aliens that are incredibly heat resistant with thick “ skin ” would live in planets near their stars or aliens that are adaptable to cold temperatures would live in planets far from their stars.

Questions, suggestions? – **Dr. Idan Ginsburg** – iginsburg@gsu.edu