Phosphorus:

Illuminating Exoplanet Habitability and the search for extraterrestrial life

While talking about a planet's habitability, we often overlook the importance of Phosphorus. But why so? We begin from the very basics- defining an exoplanet and the various factors affecting it- then we move to explain phosphorus as one of the critical factors for life. Let us start!

What is an Exoplanet?

The Planets that lie beyond our solar system are referred to as exo-planets. Most orbit another star, but some are also free-floating. Since the 1990s, we have confirmed over 5000 heavenly bodies as exoplanets, and thousands of others are under review. One of the essential features that we would like to look at in exoplanets is their habitability.

What is Habitability?

Habitability is the capability of a heavenly body to sustain at least one known organism. A habitat must ensure metabolic activity for an organism and allow its reproduction, but it is not necessary. Further, the habitat must also be able to sustain that organism.

For a long time, humanity has been conflicted over whether we are alone in the universe or not. By looking at the habitability of exoplanets, one can offer one possible solution to this conflict. Another reason we are interested in looking at an exoplanet's habitability is to make it a potential "backup" option for humans. As we know, the resources on Earth are dwindling day by day and conversely, pollution is on the rise. This may result in Earth becoming incapable of supporting life soon. Humans must shift to another planet to ensure survival in such an event. Thus, by looking at habitability, we can pinpoint which world may have Earth-like conditions and be able to sustain the human population. Lastly, systematically looking at habitability factors helps us eliminate several planets. Our resources are limited, and it is only possible to explore a limited number of exoplanets. Therefore, we can narrow the possibilities using certain constraints and find the "perfect" planet to sustain life.

What are the conditions for Habitability?

1. Solvent: A suitable liquid solvent, like water, is necessary for essential reactions and support of life. Planets with significant liquid water are categorised as surface liquid water worlds or interior fluid water worlds.

2. Physicochemical Conditions: Temperature, radiation, pressure, pH, salinity, aridity, and toxic metal levels need to be within limits for organisms to survive. Some microorganisms can withstand extreme conditions.

3. Available Energy: Organisms require energy to carry out life processes, and the environment must provide sufficient energy sources (e.g., light) for this purpose.

4. Major Elements (CHNOPS): Carbon, Hydrogen, Nitrogen, Oxygen, Phosphorus, and Sulphur are essential elements for life, each serving unique functions. Their presence in various forms is crucial for supporting life.

5. Specific Elements: Some organisms require specific elements like iron, manganese, and potassium. Life itself can alter element availability in a habitat over time.

6. Atmosphere and Planetary Factors: Mass, density, atmosphere composition, plate tectonics, and magnetic field influence a planet's suitability for life. While they help categorise habitability, they are not sole determinants.

7. Astronomical Factors: Planetary rotation, orbital characteristics, star type, and impact events impact a planet's conditions, including temperature, element composition, and overall habitability.

These factors together contribute to determining whether a planet can support life. While certain conditions are vital, the interplay of all these factors is complex, and no single factor guarantees habitability.

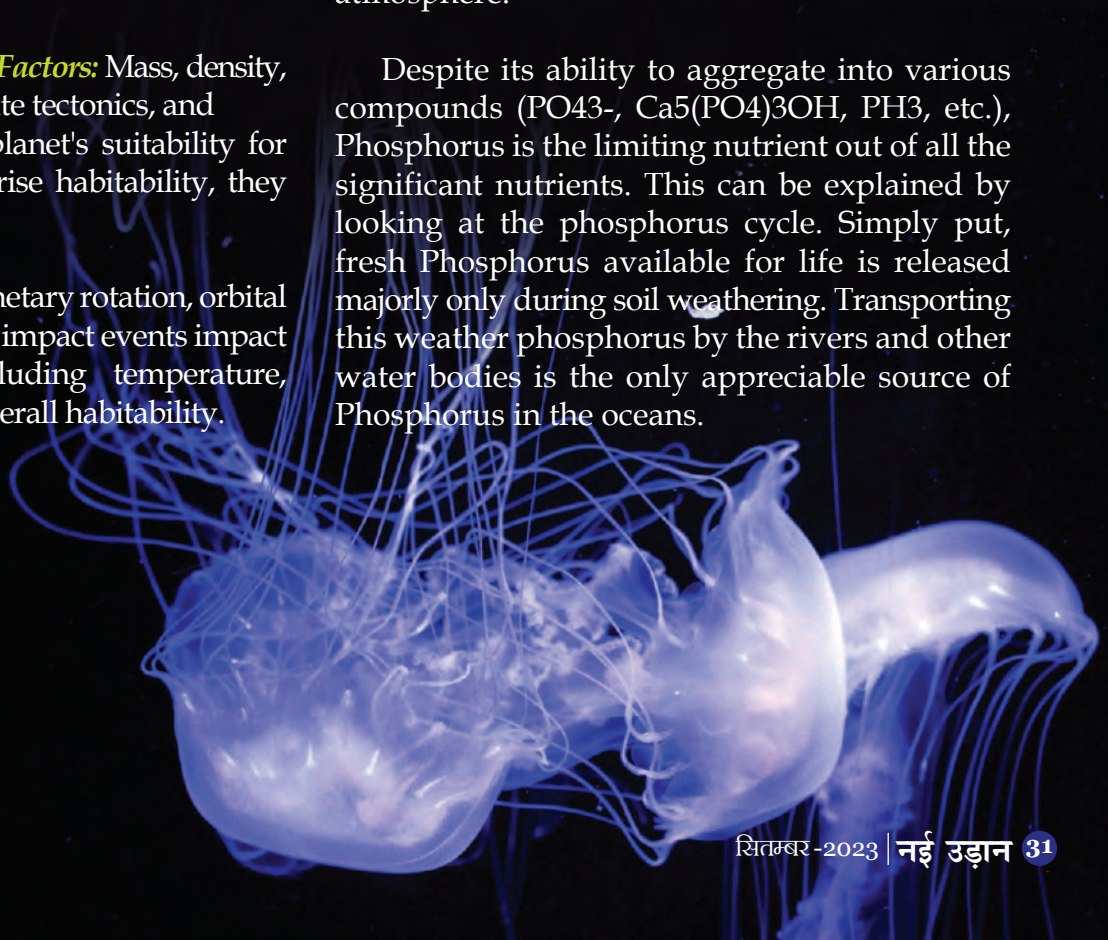
Where does Phosphorus come in?

Of all the significant elements required for life- Carbon, Hydrogen, Nitrogen, Oxygen, Phosphorus & Sulphur (CHNOPS), Phosphorus is the most unique.

Termed the "Staff of Life", Phosphorus is present in the "blueprint" all forms of life- the DNA- and forms the base of ADP and ATP, necessary for providing energy to all organisms, which is used during their metabolic processes. It is an indisposable element which played a significant role in the origin of life itself. Furthermore, Phosphorus is essential for terrestrial biological productivity and is critical to carbon balance in terrestrial ecosystems.

It is present in the form of various compounds in the environment, which may be in the soil, dissolved in water or even as a gas in the atmosphere.

Despite its ability to aggregate into various compounds (PO43-, Ca5(PO4)3OH, PH3, etc.), Phosphorus is the limiting nutrient out of all the significant nutrients. This can be explained by looking at the phosphorus cycle. Simply put, fresh Phosphorus available for life is released majorly only during soil weathering. Transporting this weather phosphorus by the rivers and other water bodies is the only appreciable source of Phosphorus in the oceans.



Ultimately, the presence of Phosphorus can limit the primary production by marine life, thus making it the "limiting nutrient." Examining whether the phosphorus cycle exists on every planet may be impossible. However, the conclusion that we can draw from here is that depending upon the phosphorus present on the top surface of a planet (soil, weathering rocks, etc.), it can be classified as potentially habitable, while the others can be rejected.

Recent studies show that ocean weathering- instead of surface weathering- may also provide sufficient concentration of Phosphorus in the oceans in the waterworlds under certain conditions. One may wonder what a waterworld is. Simply put, Waterworld is a planet with oceans- either surface or subsurface- covering a significant portion of its lithosphere. Earth is also a waterworld.

We can't detect liquid water on an exoplanet, so we use water vapour as an indicator. Before, scientists believed waterworlds whose entire surface is covered by oceans could not have phosphorus and thus are not fit for life. However, new studies suggest otherwise. Researchers now believe that waterworlds can also have unique mechanisms to recycle phosphorus and provide enough usable phosphorus to sustain life. This has made us revisit the waterworlds.

Another importance of Phosphorus is that one of its compounds- Phosphine (PH_3)- is a biosignature gas in an anoxic environment. A biosignature gas is a specific gas in an atmosphere that indicates the presence of life on a celestial body- for example, water, carbon dioxide, methane and others. No abiotic false positives on terrestrial planets have been found for phosphine. It can also be detected at no extra cost because its spectra lie in the same wavelength as other critical atmospheric molecules and biosignature gases. This makes phosphine an excellent biosignature gas. With the help of the latest technology of the James Webb Telescope, detecting phosphine gas will become easier.

Shreyan Deo

Student, 12A
DPS
Vasant Kunj

Final Thoughts

In summary, examining phosphorus as a factor in exoplanet habitability shows promise. The presence of phosphorus alters exoplanet environments, providing insights into their geology and potential habitability. Phosphine gas, a potential biosignature, could provide hint at extraterrestrial life. However, challenges include distant phosphorus detection and limited data. Future research should weigh specialised equipment development costs, time, and required expertise. This assessment will determine if the benefits of using phosphorus as a constraint outweigh the downsides. Advancements in this field promise to deepen our knowledge of exoplanets and the search for life beyond Earth.

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