

«Project Nistyak»

Beyond Sunlight: An Aquatic Chemosynthetic World

Earth's ecosystems heavily rely on sunlight, but imagine an ocean world where chemosynthesis, not photosynthesis, sustains life. Your challenge is to design such a world and its diverse ecosystem, pushing the boundaries of astrobiology beyond traditional Earth-like conditions.

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HIGH-LEVEL SUMMARY

Our project explores an alternative exoplanet, where life is sustained mostly by chemosynthesis rather than photosynthesis, showing how ecosystems go under non-Earth conditions. We invented a comprehensive model of the planet, with its special cosmic location, the cycle of elements, chemical processes and unique lithosphere and hydrosphere which allows life to arise. By positioning the planet at the optimal distance from the star to maintain fluid, we show how an exoplanet can develop under such conditions. The planet's elemental cycle contains sulfur and methane as crucial elements, involved in chemosynthetic reactions in hydrothermal vents. Our team's model shows the specialized ecosystems like diverse organisms that have evolved to harness chemical energy from the planet's hydrothermal activities. These ecosystems mimic Jupiter's satellite, Europa deep-sea and thick ice cover on the surface but extend to greater complexity and adaptability. This project is significant because it expands our understanding of astrobiology and demonstrates how life might exist on different conditions from our Earth, helping future extraterrestrial exploration and the search for different life systems in the universe.

INTRODUCTION

Our project envisions an ocean-covered exoplanet where life thrives through chemosynthesis—using chemical energy instead of sunlight. This unique world has been designed with specific conditions, including its cosmic location, element cycling, and interaction between life and its geology. These concepts challenge traditional views of habitability and offer insights into how life could exist in extreme, non-Earth environments.

Cosmic Location and Planetary Structure

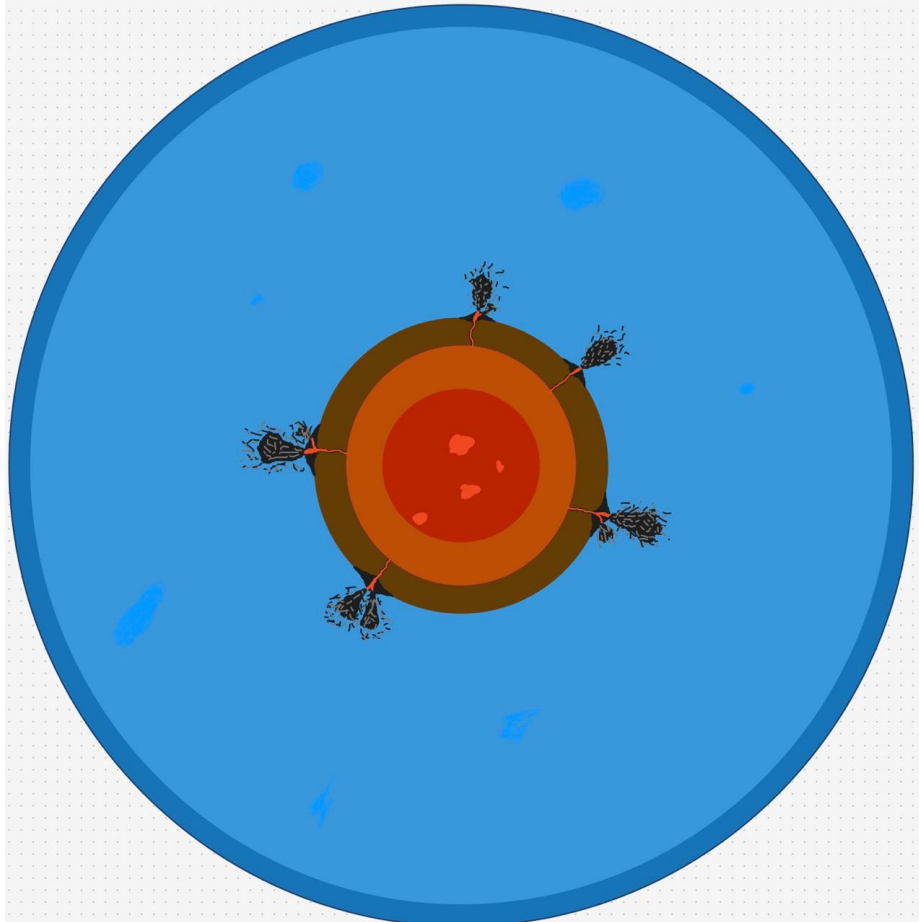
The planet orbits between 0.8 and 1.5 AU from its attractor, maintaining liquid water and stable climates. Its nearly circular orbit and axial tilt ensure minimal seasonal fluctuations. Nearby planets and moons create gravitational forces that influence the planet's geological activity, such as the development of hydrothermal vents and volcanic eruptions. These factors create a complex planetary system, where its orbit and geological activity constantly interact.

The surface is covered by a thick, icy shell that insulates the mineral-rich ocean beneath it. This thick ice layer protects the ocean from harsh external conditions and stabilizes the environment. Temperatures in the ocean range from freezing near the surface to nearly boiling near hydrothermal vents on the ocean floor, enabling diverse life forms to thrive despite extreme conditions.

Lithosphere, Hydrosphere, and Geological Processes

Below the icy surface, the planet's lithosphere consists of tectonic plates, creating the necessary conditions for hydrothermal vents to form. Active tectonics at the ocean floor give rise to volcanoes and hydrothermal vents, releasing chemicals like hydrogen sulfide (H_2S), carbon dioxide (CO_2), and iron (Fe^{2+}) into the ocean. These chemicals are fundamental for chemosynthetic life.

The planet's core, much like Earth's, is composed of iron (Fe) and nickel (Ni), generating a strong magnetic field that protects the planet from cosmic radiation and drives internal heat. This heat sustains volcanic activity and convection currents in the mantle, which fuel the formation of hydrothermal vents. These vents play a key role in sustaining the planet's nutrient cycles and supporting life without the need for sunlight.



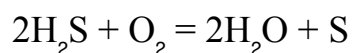
1st picture, model of the planet

Elemental Cycles and Geothermal Processes

Life on the planet relies on energy from hydrothermal vents, which release chemicals vital for sustaining ecosystems. Chemosynthetic bacteria thrive by utilizing the oxidation of these chemicals, forming the foundation of the planet's food chain.

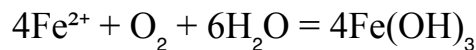
The key chemical reactions driving life include:

1. Oxidation of hydrogen sulfide (H_2S):



This reaction provides energy for chemosynthetic bacteria by converting hydrogen sulfide and oxygen into water and elemental sulfur, forming the base of the food chain near hydrothermal vents.

2. Oxidation of iron (Fe²⁺):



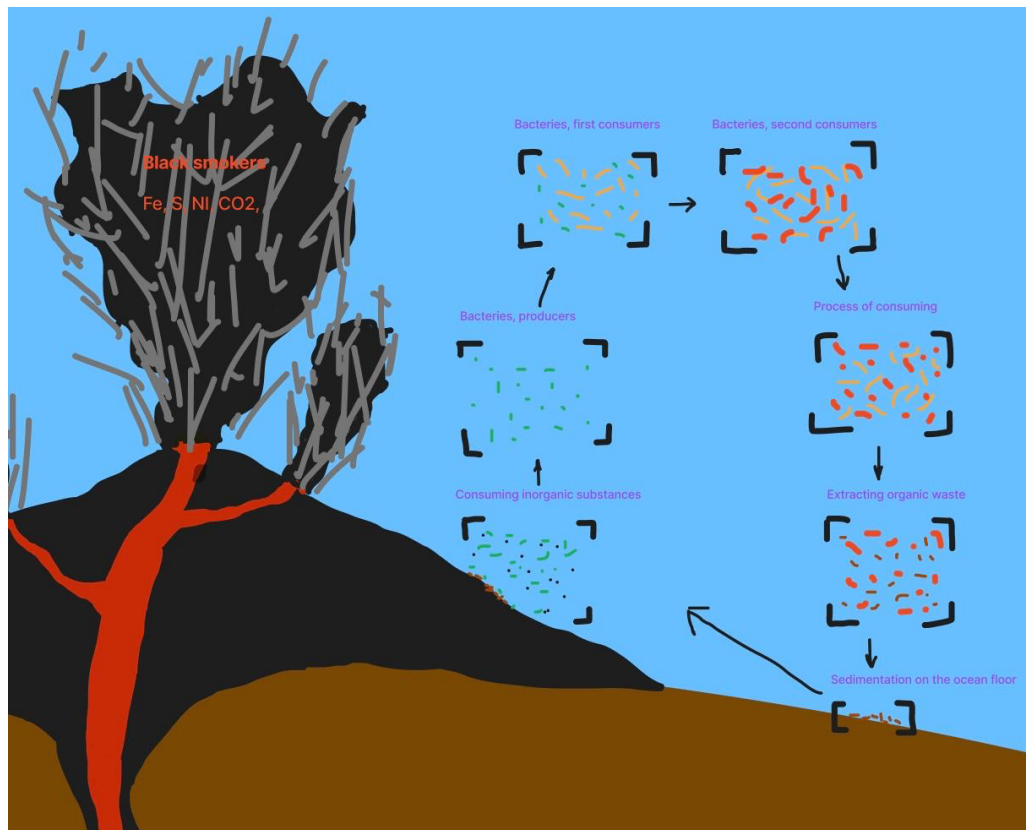
In this reaction, iron oxidizes in the presence of water and oxygen to produce iron hydroxide, another critical process for bacteria living near the vents.

These reactions create energy that allows bacteria to convert inorganic chemicals into organic matter, powering the planet's ecosystems. In the carbon cycle, chemosynthetic bacteria absorb CO₂ directly from the water, converting it into organic compounds. When these bacteria and other organisms die, the carbon is released back into the ocean as CO₂, continuing the cycle. Nitrogen also cycles through the ocean via bacteria that convert ammonia into nitrates, which are then used by other organisms.

Ecosystem and Adaptation

The ecosystems on this planet are highly specialized, having evolved to thrive in sunless, chemically rich environments. Chemosynthetic bacteria form the base of a food chain that includes tiny, tube-dwelling worms and larger predators. Unlike Earth's ecosystems, which rely on sunlight and photosynthesis, life here depends entirely on chemical energy from geothermal sources.

Many organisms have evolved to withstand the extreme conditions near hydrothermal vents, such as high pressure, low pH, and extreme temperatures. Some organisms have symbiotic relationships with chemosynthetic bacteria, allowing them to access chemical energy directly. This mirrors some deep-sea ecosystems on Earth, but life on this exoplanet has adapted to even harsher conditions.



2nd picture, ecosystem of the planet

Nutrient Cycle and Adaptations of Microorganisms

The nutrient cycle on this planet is self-sustaining, ensuring stability within its ecosystems. Chemosynthetic bacteria generate organic matter through chemical processes, while multicellular organisms, such as filter feeders and detritivores, feed on these bacteria. Decomposers, in turn, break down dead organisms, releasing inorganic elements like carbon dioxide and water back into the environment.

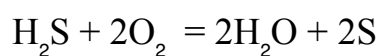
Microorganisms have evolved to survive in extreme conditions. Their cell membranes are resistant to acid due to modified lipids, while their cell walls are fortified with minerals. Specialized proteins within their cytoplasm stabilize cellular structures under immense pressure, preventing denaturation and supporting their survival near hydrothermal vents.

Geological and Chemical Activity

Geothermal processes and tectonic activity drive the formation of hydrothermal vents, which release essential chemicals like hydrogen sulfide and iron into the ocean. These vents create localized ecosystems where bacteria thrive. The chemical reactions near the vents, such as the oxidation of hydrogen sulfide and iron, provide energy that sustains life.

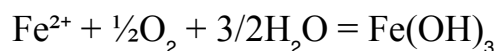
Other important reactions include:

3. Oxidation of hydrogen sulfide in water:



This oxidation releases water and sulfur, forming the chemical energy that fuels the planet's biosphere.

4. *Further oxidation of iron (Fe^{2+}):



This reaction enables bacteria to extract energy from iron in the ocean, supporting the unique ecosystems around the hydrothermal vents.

These reactions, occurring near the planet's geothermal sources, are crucial for maintaining the flow of energy through its ecosystems.

Evolutionary Processes and Potential for Intelligent Life

Evolution on this planet has followed a path of adaptation to its extreme, underwater conditions. The isolated ecosystem fosters the development of organisms with no analogs on Earth. The high acidity, extreme pressure, and absence of sunlight have led to life forms that are specialized for survival in this unique environment.

With the abundance of chemical energy, there is potential for intelligent life to evolve. Such life forms could develop symbiotic relationships with bacteria, allowing them to control energy flows within their bodies through advanced biochemical processes. These intelligent organisms might manipulate chemical reactions to fuel complex metabolic processes, marking a different evolutionary trajectory than life on Earth.

Astrobiological Implications

This project challenges traditional notions of habitability, expanding the potential locations where life could thrive. By focusing on a world sustained by chemosynthesis, we consider the possibility of discovering life on similar environments, such as the icy moons Europa and Enceladus, where subsurface oceans may harbor life fueled by hydrothermal activity.

The discovery of chemosynthetic ecosystems beyond Earth would significantly alter our understanding of life in the universe. This shift from solar radiation to chemical energy as a primary energy source broadens the scope of astrobiological exploration.

Exploration and Colonization Potential

The study of this oceanic exoplanet presents exciting opportunities for future space exploration. Similar to Europa and Enceladus, this planet's deep ocean ecosystems are sustained by chemical reactions, rather than sunlight. Robotic missions could explore these environments and search for signs of life. However, the planet's extreme conditions, such as low temperatures and high acidity, make colonization unlikely without advanced technologies.

CONCLUSION

Our project reshapes how we look at habitability and the search for extraterrestrial life. By focusing on chemosynthesis, we explore a world where life flourishes without sunlight, relying instead on chemical reactions and geothermal energy. This concept broadens our understanding of where life could exist, offering new hope for discovering alien ecosystems in environments previously thought to be too hostile.

The implications for astrobiology are immense, challenging the traditional assumption that sunlight is necessary for life. As we continue to explore both real and imagined extreme environments, we push the boundaries of where life might thrive, increasing our chances of discovering extraterrestrial life in unexpected places.

USE OF ARTIFICIAL INTELEGENCE:

Our team used Artificial Intelligence, especially for gathering information and finding credible sources. AI made the research much faster than we estimated, so it got easier to explore a wide range of recources about the features of different planets, like atmospheres, geology and how life might survive in extreme conditions. This was essential in figuring out the right qualities for the planet we imagined. With AI, we were able to compare various planetary characteristics, such as where liquid water might exist or how geothermal activity could support life. It helped ensure that the planet we designed was based on solid science and not just imagination.

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