The Habitability of Our Earth and Other Earths: Astrophysical, Geochemical, Geophysical, and Biological Limits on Planet Habitability

Paper Report

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1 What phenomenon is being studied, and what is its significance?

The phenomenon being studied in this paper by **Charles H. Lineweaver and Aditya Chopra** is the **habitability** of planets in and outside of our solar system using the knowledge we know about earth as a habitable planet.

A planet's habitability, or ability to harbor life, results from a complex network of interactions between the planet itself, the system it's a part of, and the star it orbits.

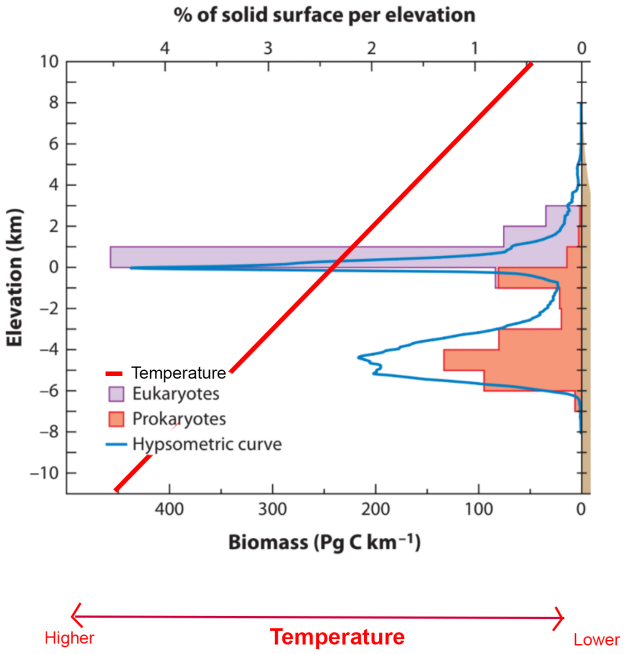
It uses the knowledge we have about life from microbiology which dictates the necessary conditions for the origin and development of life on a planet to the astronomical constraints required to support such conditions. Recent exoplanet detections tell us that almost all stars have planets. Therefore, studying these array of parameters that are required to support life may help us find other habitable worlds which would help us survive as a species.

Understanding the origin of life can be tough and will perhaps remain a mystery to mankind forever.
However, according to the **Copernican principle**, the universe is isotropic(same in all directions) when observed on large scales. In other words, there is nothing special about planet earth. Therefore there must be other habitable planets in the universe considering the size of the universe and the study of this phenomenon is surely significant and meaningful.

2 What is known about the phenomenon?

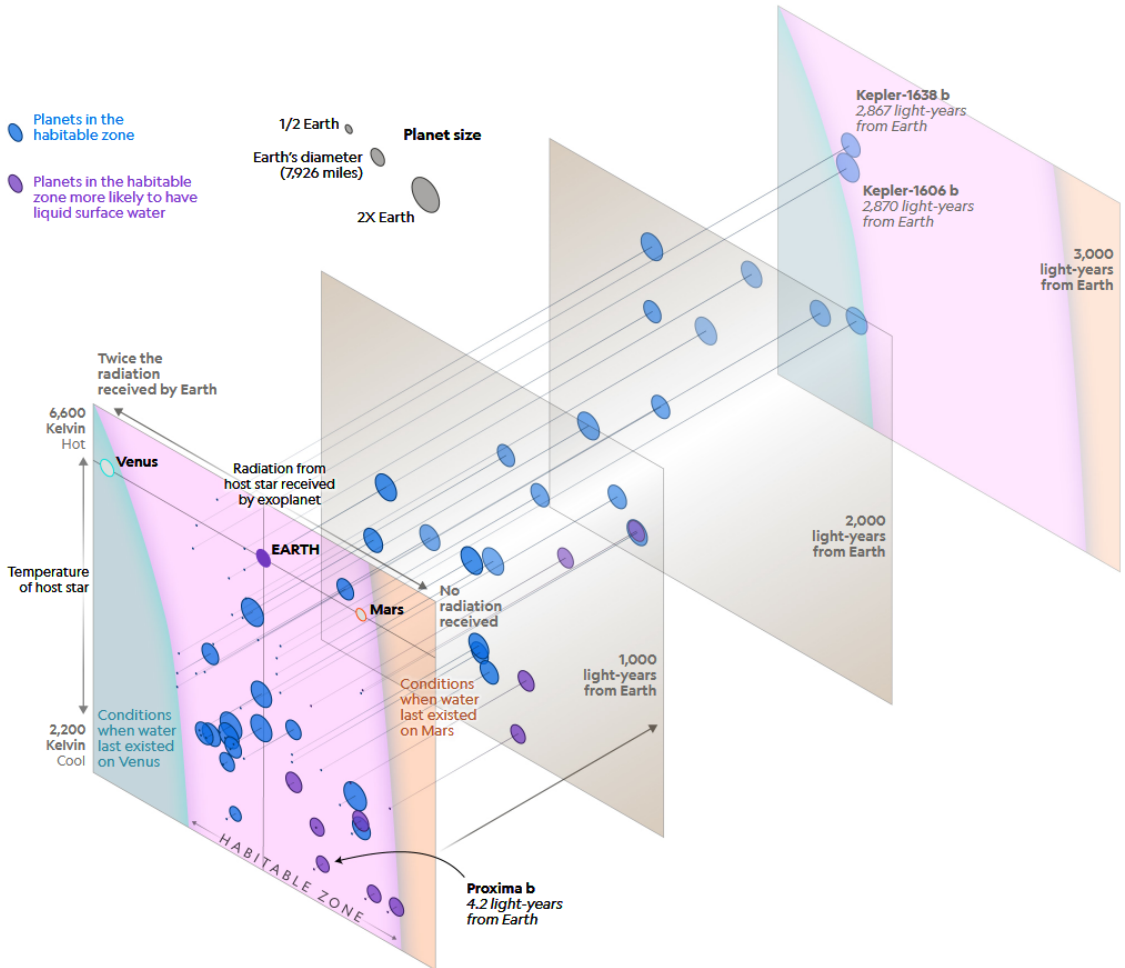
2.1 Habitability on Earth

- The persistence of life requires liquid water, an appropriate temperature range, nutrients, and an energy source.
- Life of earth is not uniformly distributed.There are water deserts, low-temperature deserts, nitrate deserts, and iron deserts, where the abundance of life is significantly lower than in surrounding regions.
- The conditions needed for the origin of life(**Abiogenesis Habitable Zone**) are much more narrower than the conditions needed to support it because:
  a) Life itself can adapt to its surroundings,
  b) Life can modify the environment its in to sustain itself, and
  c) Self-assembly is an additional requirement for Abiogenesis.
- Life on Earth is found mostly between $\pm$ 10 km of earth's surface
- According to the RNA world hypothesis life evolved from non living chemicals hence there was a form of 'pre-cellular life'. During its earlier days, the Earth lacked eukaryotes and consisted only of prokaryotes. The rate of evolution of life accelerated at the end of the last 'snowball Earth' about 600 million years ago.
- An alternative to the chemical origin of life is panspermia which states that life on earth may have formed extra terrestrially.
- The earlier life was probably chemotropic(contrasting to today's 60% phototrophic and 40% chemotropic), which gained energy from redox reactions(less energetic).
- The increasingly large overlap between terrestrial environments known to harbor life and the surface environments of newly detected rocky exoplanets bolsters expectations that the universe may be filled with habitable planets.



2.2 Planets and exoplanets

The fraction of stars with planets is approximately 100%. The fraction of stars with a rocky planet in the Habitable Zone could be comparably large.
Based on Kepler's results approximately 100% of stars have a Earth like planet.



2.3 Water and Temperature as the primary parameters

1) Life as we know it is water based. It is a natural solvent for dissolving various chemicals and transport of nutrients.
2) The right temperature is required to maintain the liquid state of water and also provide conditions necessary for various organic reactions to occur

Factors that make a Planet Habitable	Not Enough of the Factor	Just Right	Too Much of the Factor
Temperature *Influences how quickly atoms & molecules move*	Low temperatures cause chemicals to react slowly, which interferes with the reactions necessary for life. Also low temperatures freeze water, making liquid water unavailable.	Life seems limited to a temperature range of minus 15°C to 115°C. In this range, liquid water can still exist under certain conditions.	At about 125°C, protein and carbohydrate molecules and genetic material (e.g., DNA and RNA) start to break apart. Also, high temperatures quickly evaporate water.
Water *Dissolves & transports chemicals within and to and from a cell*	The chemicals a cell needs for energy & growth are not dissolved or transported to the cell	Water is regularly available. Life can go dormant between wet periods, but, eventually, water needs to be available.	Too much water is not a problem, as long as it is not so toxic that it interferes with the chemistry of life

2.4 Galactic constraints

Certain constrains dictate where life can be formed in our galaxy:

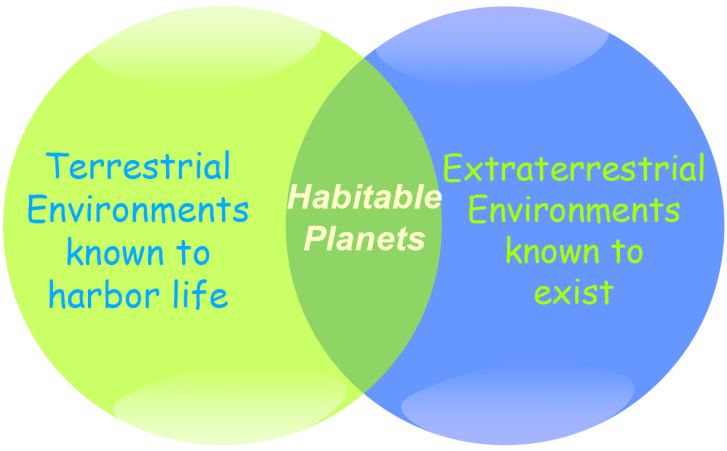
- The presence of a host star.
- Enough heavy elements to form terrestrial planets.
- sufficient time for biological evolution (approx. 4 billion years).
- An environment free of life-extinguishing supernovae.

These constraints define the Galactic Habitable Zone (GHZ).

3 What methods are used to obtain the above knowledge about the phenomenon?

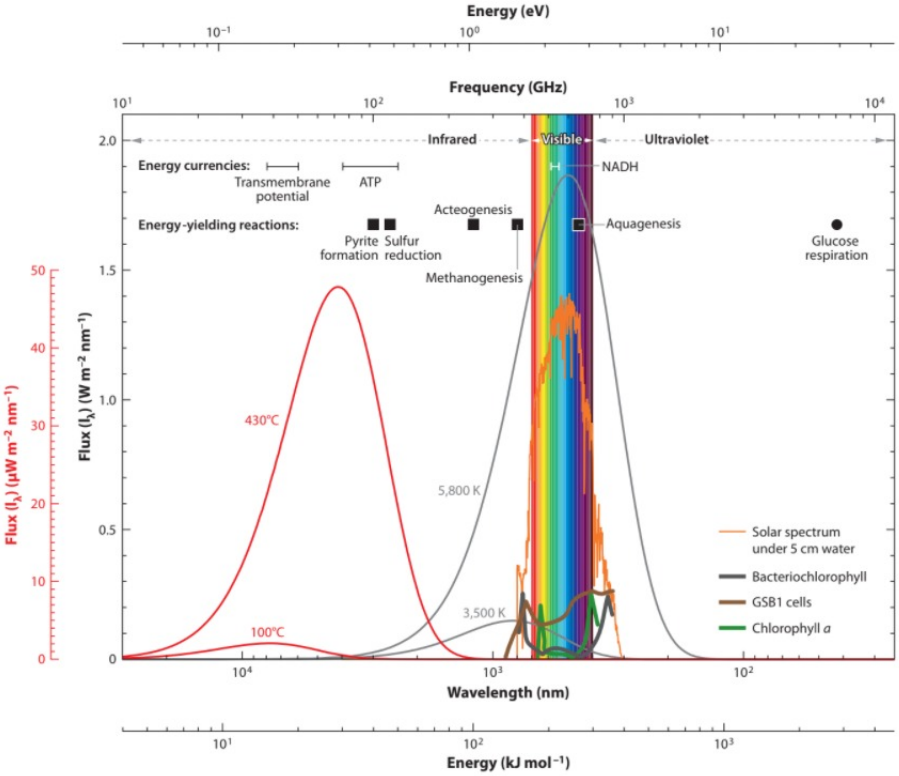
3.1 Conditions for habitable planets as a overlap of 2 sets

Habitable planets are emerging from the increasing overlap of two sets of environments: the increasingly large set of terrestrial environments known to harbor life and the increasingly large set of extraterrestrial environments on the newly detected rocky exoplanets.

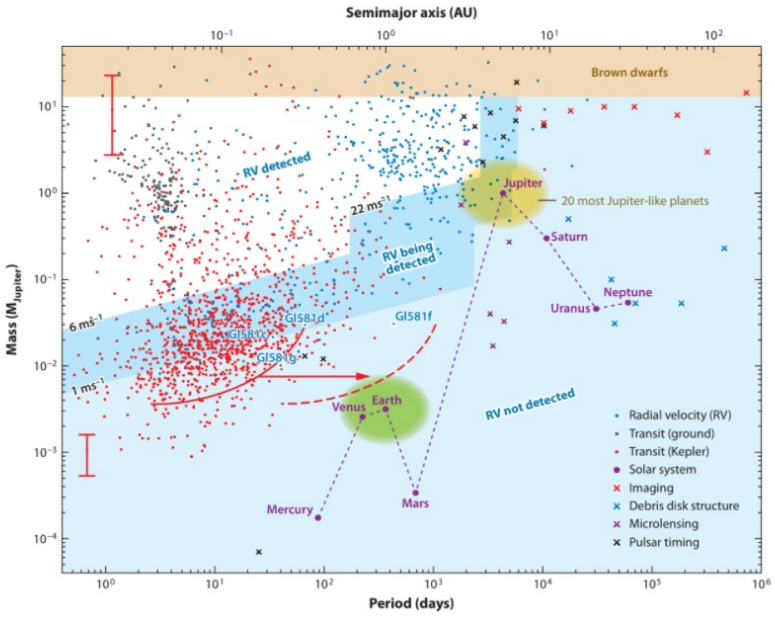


3.2 Comparing Energetics

The similar energies of the earliest metabolic pathways and the availability of the reactants in environments such as hydrothermal vents prove that life began by using energy sources based on redox gradients(chemotropic) and over time evolved to perform higher-energy reactions(phototrophic) such as oxygenic photosynthesis and oxic respiration.



3.3 Exoplanet finding techniques



- This figure mainly represents instrument sensitivity rather than actual data.
- The white RV detected region is a real pattern
- We can see that Jupiter radius like planets have masses similar to Jupiter
- Planets with low time period are uncommon

By studying their surface temperatures and albedos we can define a circumstellar habitable zone for planets by comparing their parameters to that of Earth.

4 What uncertainties accompany the above methods?

4.1 Abiogenesis Habitable Zone(AHZ) smaller than Habitable Zone(HZ)

The habitability requirements for the origin of life are substantially different from, and more specific than, the requirements to maintain life on a planet thus even if the planets satisfies conditions in 3.1, it may not have life.

4.2 Technological Limitations

Exoplanet detections have technique dependent limitations. Each technique of identifying exoplanet can only find them in a certain range, under certain constraints.

4.3 Uncertainty in primary parameters

- Water content depends on many variables: the C/O ratio of the star, the number of impacts with water-rich planetesimals(which depend on planetary position and planetary mass).
  Water content on a terrestrial planet can vary typically by factors of a few and probably much more when more parameters are allowed to vary.
- Variations in a planets ability to hold water. We suspect that the Earth might have had lot more water earlier.

5 What questions remain open?

The definition of life itself remains open. Until we can completely define the conditions necessary for life and what exactly is living, we need to continue doing our research.

We need to advance our techniques of identifying exoplanets and study other planets especially the Martian subsurface and gather more data to produce a good theory on habitability.
Such techniques should be able to distinguish between biotically and abiotically produced atmospheric chemical disequilibria on the nearest terrestrial exoplanets.

The question: **Are we alone in the universe?** still remains open and even if the answer to this question is false, we need to continue to study the habitability to planets to ensure our survival as a species.

References

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