The Venus Life Equation

Noam Izenberg[1], Diana M. Gentry[2], David L. Smith[2], Penelope J. Boston[2], David Grinspoon[3], Grzegorz Slowik[4], Mark Bullock[5], and Martha Gilmore[6]

[1]JHU Applied Physics Laboratory
[2]ARC
[3]PSI
[4]Univ. Zielona Góra
[5]Sci. Tech. Corp.
[6]Wesleyan University

November 21, 2022

Abstract

Does life currently exist, or did life once exist, on other worlds in our solar system? The proximity of the rocky planets of our solar system, Venus and Mars, make them obvious targets for the first attempts to answer these questions via direct exploration, with concomitant implications for, and input to, how we think of exoplanets. Given the limited resources we have to explore our neighbors in space, an ecological assessment (based on terrestrial ecosystem principles) might help us target our search and methodology. Studies of extreme life on Earth consistently reveal adaptability. Mars has been the target of many life-related investigations [1, many others]. Venus has not, yet there may be compelling reasons to think about extant life on the second planet [2], and lessons to learn there about searching for life elsewhere in the solar system and beyond. The Venus Life Equation: Venus may have been habitable for billions of years its history and may still be habitable today. Our current state of knowledge of the past climate of Venus suggests that the planet may have had an extended period – perhaps 1-2 billion years – where a water ocean and a land ocean interface could have existed on the surface, in conditions possibly resembling those of Archaean Earth [3]. At present, Venus' surface is not hospitable to life as we know it, but there is a zone of the Venus middle atmosphere, ˜55 km altitude, just above the sulfuric acid cloud layer, where the combination of pressure, temperature, and gas-mix are more Earth-like than anywhere else in the solar system [2, 4]. The question of whether life could have – or could still – exist on the Earth's closest neighbor is more open today than it's ever been. Here we approach the question of present-day life on Venus in a manner analogous to the Drake Equation [5], treating the possibility of current Venus life as an exercise in informal probability – seeking qualitatively the likelihood or chance of the answer being nonzero.The working version of the Venus Life Equation is expressed as: L = O * R * A where L is the likelihood (zero to 1) of there being life on Venus in the present-day, O (origination) is the chance life ever began and "broke out" on Venus, R (robustness) is the potential current and historical size of diversity of the Venus biosphere, A (acceptability) is the chance that conditions amenable to live persisted spatially and temporally to the present. The Venus Life Equation is a work-in-progress as a pre-decadal White Paper [6] and its variables are currently being refined. [1] McKay 1997, Springer, Dordrecht, 1997. 263-289. [2] Limaye et al. 2018 Astrobiology, 18(9), 1181-1198. [3] Way et al. 2016 JGR 43(16) 8376-8383. [4] Schulz-Makuch et al. 2004 Astrobiology 4, 11-18. [5] Burchell 2006, Int. J. Astrobio, 5(3) 243-250. [6] Izenberg et al. 2020, https://is.gd/vd4JE7 (location of Latest version of Venus Life Equation White Paper).

The Venus Life Equation

Noam R. Izenberg[1] (noam.izenberg@jhuapl.edu; @izenplanet), Diana M. Gentry[2], David J. Smith[2], Penelope J. Boston[2], David Grinspoon[3], Grzegorz Slowik[4], Mark Bullock[5], and Martha Gilmore[6]

[1]Johns Hopkins Univ. Applied Physics Laboratory, Laurel, MD, USA, [2]NASA Ames Research Center, Moffett Field, CA, USA, [3]Planetary Science Institute, Washington, DC, USA, [4]University of Zielona Góra, Poland, [5]Science and Technology Corp., Boulder, CO, USA, [6]Wesleyan University, Middletown, CT, USA

Johns Hopkins Applied Physics Laboratory — Space Exploration

Ames Research Center

PSI

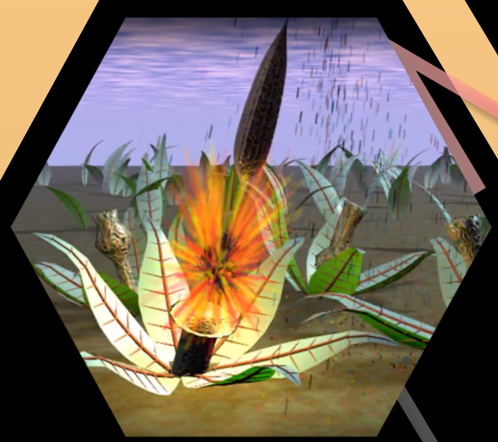
Lunar and Planetary Science Conference

Abstract #1512

Life on Venus? Really?

Venus has a hot "Gas Ocean" unique in the solar system. In the Earth's fluid ocean, most organisms are attached to particles, floc, etc. In Earth's atmosphere, organisms typically are also attached to particles. Most biomass in Earth's oceans femto- to pico-plankton size (<0.2 μm-2 μm). Sulfur-based photosynthesis is thought to be one of the first forms of photosynthesis on the Earth.

START



Karl Sims (1990) Panspermia

Origination: The chance life both began and "broke out" on Venus.

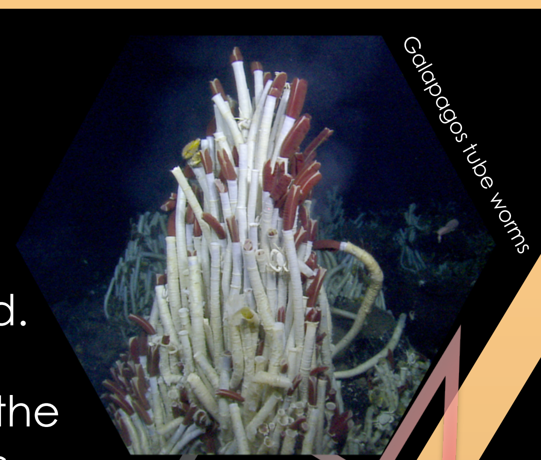
Life on a planet can start via independent abiogenesis, or importation from elsewhere (panspermia) or:

$O_A + O_P$, or possibly:

$1 - ((1 - O_A) \cdot (1 - O_P))$

where O_A is the likelihood of origin by abiogenesis and O_P is the likelihood of origin by panspermia. In our own solar system, for lack of definitive evidence, we assign $O_A \sim 1$ for Earth, and ? for other bodies. O_A depends on how "easy" life is to arise. O_P in our solar system can be nonzero from possible transportation of life due to impact from Earth, at the very least. Venus is the most likely to receive viable life from Earth, and thus, over geologic history, we can hazard a value of $O_P \sim 0.1$-0.5. But just *starting* life is not enough.

Breakout: The chance escaped its point of origin to spread across the planet.



Galapagos tube worms

On earth life may have arisen, dozens, or thousands of times in different pools or fumaroles, only to be snuffed out by random events and changes, of which we have no record. Life is only detectable if it breaks out of its point of origin, and spreads across the planet. This is encapsulated in the variable O_B, which for Earth is became 1 early in its history, though we can likely never know how many false starts life had here. If we assume early Venus was similar to Archean Earth for 2+ billion years, an O_B of 0.9 to 1 may be reasonable. Accounting for breakout as well as start of life make the Origination term a little more complex:

$$O = (O_A + O_P) \cdot O_B \text{, or :}$$

$$O = (1 - ((1 - O_A) \cdot (1 - O_P))) \cdot O_B$$

On Venus, our estimations for the subfactors give a range for O of 0.09 to 0.4, a possibly conservative to probably generous estimate for life getting a foothold on the second planet.

Robustness: the potential current and historical size and diversity of the Venus biosphere.

Life on Earth has survived in part because it spread so wide, with such variety and quantity, that it was hard to completely eradicate. An estimation of Robustness may be expressed with:

$$R = R_B \cdot R_D$$

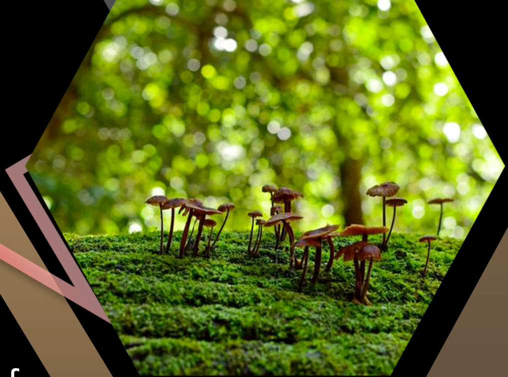
where R_B is a measure of potential biomass supported, and R_D is a measure of potential Diversity. On Earth, Biomass has been sufficient to allow survival of dramatic climatic change and near-global extinction events. Perhaps early Earth is a reasonable template for estimating R_B for early Venus; between 0.5-0.8.

Arctic fox

Current Venus is more constrained by sheer mass available *for* biomass; even imagining every cloud or haze particle in the Venus atmosphere is actually an organism gives a number of organisms several orders of magnitude lower than for Earth.

Diversity includes functional, lineage, genetic, and more.

On Earth, nearly every liquid and solid surface is colonized, though some harsh niches are sparsely inhabited and predominantly inactive: R_D approaches 1. Yet one of the few places we don't see a full life cycle (gestation, growth, and reproduction) is in the upper atmosphere. Is this due to a lack of continuous selection pressure and residence, or is not even life on Earth robust enough to conquer this hostile zone? Again using early Earth as a template and picking a range of 0.25-0.6 for R_D, we get a range for R between 0.125 and 0.51.



Biodiversity

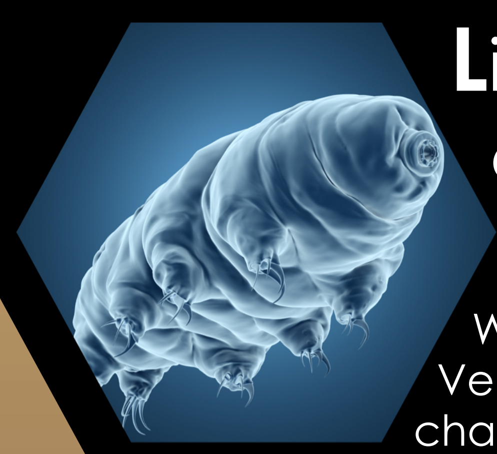
Does life currently exist on Venus?

In absence of direct in-situ investigation, the study of extreme environments on and in Earth, coupled with what we have measured, modeled, and extrapolated for Venus enable attempts at answering this question, with implications for how we think of life on other worlds.

$$L = O \cdot R \cdot A$$

The Venus Life Equation is an exercise in Informal probability, seeking qualitatively a method for estimating the chance for extant life on the second planet, and perhaps elsewhere.

What is your estimation?



Gratuitous tardigrade (PBS)

Life: The Net chance life exists today on Venus.

With estimates for all 3 factors for Venus, we can calculate a range for the chance of life. Using the high and low values throughout:

L = 0.09 * 0.125 * 0.1 ~ 0.001 (low) or

L = 0.4 * 0.51 * 0.5 ~ 0.1 (high)

This exercise can be performed for any potential abode of life in our solar system, and adapted and estimated for any potential habitable world.

f_l

The L determined by of the Venus Life Equation, adapted for and integrated over many possible worlds, is related to the term f_l of the Drake Equation: the fraction of planets in our galaxy that develop life. The equation applied to Venus shows how we might approach questions of habitability on worlds beyond Earth

Acceptability: the chance that conditions amenable to life persisted spatially and temporally to the present.

This factor reflects the necessity of continuous existence of habitats over time and space. This factor is the most quantifiable for Venus through direct measurement; determining the of current resources in potential niches (e.g. The elements C, H, N, O, P, & S and solvents in Venus clouds), and through unraveling the geologic history of the planet to determine if a continuous path might have been available for life to evolve to survive and maintain itself for tens or hundreds of millions of years of post-ocean Venus history. If, for example, life had evolved to survive in the Venus clouds as we know them today. This factor is hard to estimate given how little we know about both Venus' history and current potential habitats. Assigning for A a range of 0.1 to 0.5 may be generous, or not.

David Latimer's 40 year terrarium.

The B.O.C.L.

Boston Operational Checklist of Life

- Boundary conditions
- Pattern and its persistence
- Energy flow through system
- Energy & material acquisition
- Disequilibria with environment
- Internal lowering of entropy
- Homeostasy • Complexity
- Information content • Autopoiesis
- Non-crystallographic growth
- Reproduction of similar units
- Evolvable, respond to changes

References

Way *et al.*, 2016 *JGR* 43(16) 8376-8383; Limaye *et al.*, 2018 *Astrobiology*, 18(9), 1181-1198; Burchell 2006, *Int. J. Astrobio*, 5(3) 243-250; Knollenberg & Hunten 1980, *JGR Sp.Phys.*, 85 A13; Izenberg *et al.*, 2020, https://is.gd/vd4JE7 (Latest version of White Paper).

Acknowledgements

This abstract builds on the ongoing work of the Venus Life Equation pre-Decadal White Paper team and feedback from the planetary/exoplanetary science community from The Exoplanets In Our Backyard workshop.