# Evolution of a Possible Biosphere on Venus

David Grinspoon
Planetary Science Institute

International Venus Conference
5/31/19

*New York Times* 11/16/1928

## SAYS LIFE MAY BE ON VENUS

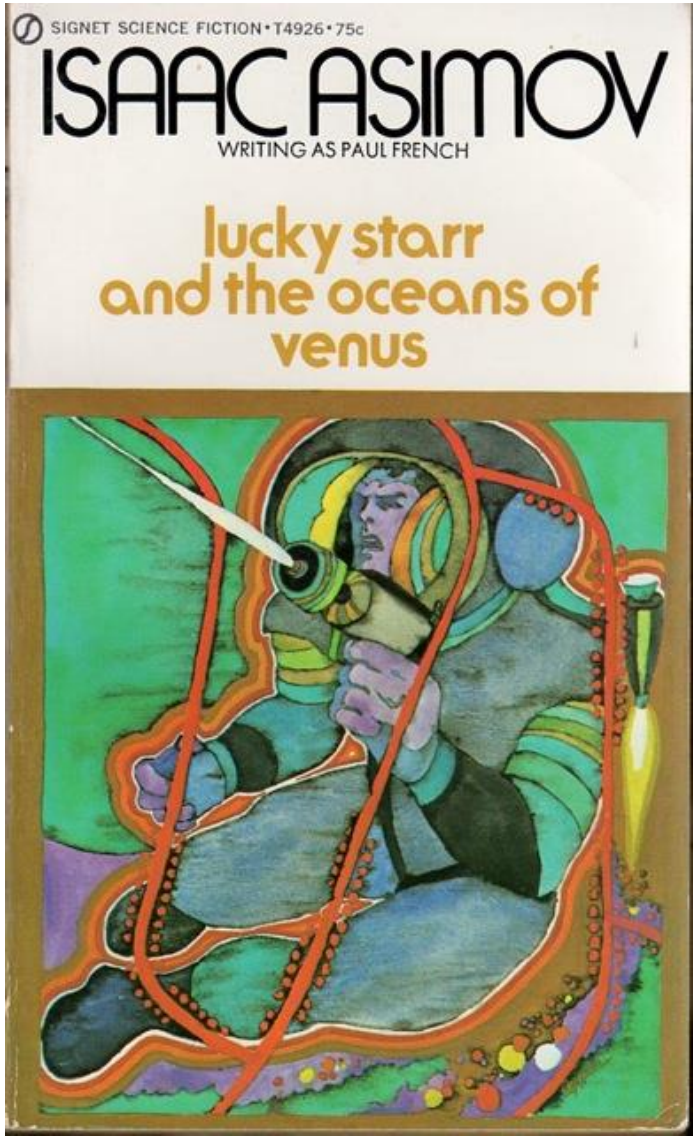
### Cambridge Savant Believes Mars Also Has Essentials for Existence.

Special Cable to THE NEW YORK TIMES.

LONDON, Nov. 15.—That life may exist on both Venus and Mars is the conclusion reached by Dr. A. S. Eddington, professor of astronomy at Cambridge. In a book to be published tomorrow he says that Venus, so far as is known, would bewell adapted for life similar to ours. The planet is about the same size as the earth, nearer the sun but probably not warmer, and possesses an atmosphere of satisfactory density.

As regards Mars, Professor Eddington says that the two essentials, air and water, are both present but scanty. The Martian atmosphere is thinner than ours, but perhaps adequate. It has been proved to contain oxygen.

If animal life exists on that mysterious planet, he says, it probably is a different form of life from ours, as "Mars has every appearance of being a planet long past its prime."



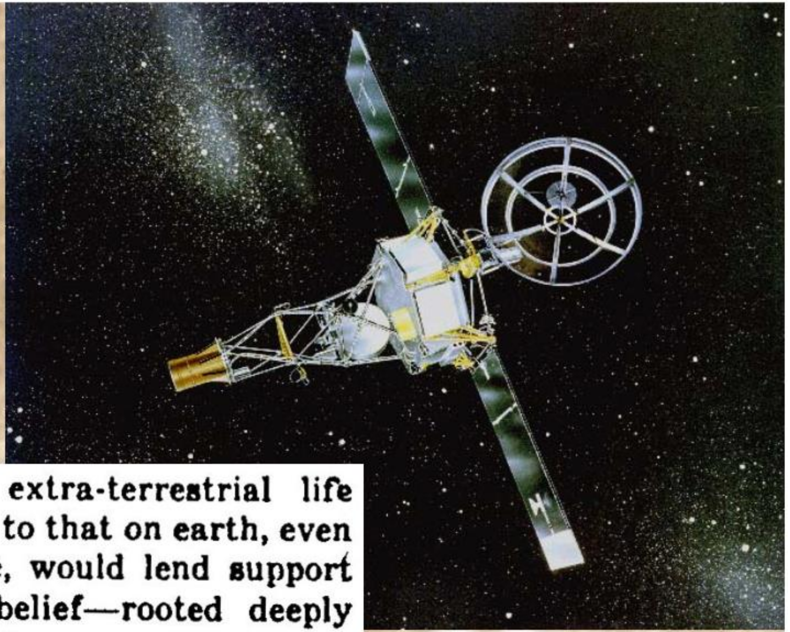
*New York Times 2/26/1963*

## Venus Says 'No'

The first message from the Venus probe, Mariner 2, deciphered shortly after its historic fly-by of the planet on Dec. 14, at a distance of 21,564 miles, added important knowledge about Venus's magnetic field, its rate of rotation and other information shedding light on some of its mysteries. But one all-important question remained unanswered—whether or not life in some form existed on Venus and hence elsewhere in our solar system and possibly also beyond it.

Now comes a second message from Venus, via Mariner 2, with the first definite eagerly-awaited answer to this vital question, and the answer is a disheartening, disillusioning "No! Not on Venus!"

The newest message from Venus, sent down by the "cosmic thermometer" on Mariner 2, which made the first direct measurements of the surface temperature of the planet, informs earthlings that the temperature at or near the surface of our cloud-covered, planetary neighbor is between 300 and 400 degrees Fahrenheit. This high temperature, established for the first time, definitely rules out the possibility of the existence of life in any form even remotely resembling life as we know it on earth.



The finding of extra-terrestrial life in some form similar to that on earth, even at the lowliest stage, would lend support to the widespread belief—rooted deeply in the aspirations of mankind—that life as we know it is not unique to this insignificant corner of the universe, but exists in many other systems similar to ours throughout the universe. Indeed, there has been speculation among scientists, philosophers and poets that some of these systems have reached a stage of evolution much superior to ours. The message from Venus now reduces the hope of finding evidence in support of this speculation to one half, so far as our solar system is concerned.

Mars now remains our only hope of turning this universal dream into reality, and the evidence so far is not very encouraging. The message from Venus may mark the beginning of the end of mankind's grand romantic dreams.

# Longevity of an Early Venus Ocean?

Kasting (1988) in many ways optimized to get rid of ocean quickly:

- Calculations produce **upper limit** on surface temperatures (and therefore upper limit on escape fluxes, and lower limit on lifetime of ocean).
- **Clouds excluded.** No cloud feedback which, qualitatively, is expected to stabilize surface temperatures with rising solar flux, and therefore extend the lifetime of the moist greenhouse.
- New results (Way et al., 2016) suggest that the oceans of Venus may have persisted for ≈ 2 Gy. Venus may have been a habitable planet (with an oxygenated atmosphere?) for much of Solar System history.

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2016GL069790

**Key Points:**
- Venus may have had a climate with liquid water on its surface for approximately two billion years
- The rotation rate and topography of Venus play crucial roles in its surface temperature and moisture
- Young Venus-like exoplanets may be considered candidates for the search for life beyond Earth

**Correspondence to:**
M. J. Way,
michael.j.way@nasa.gov

**Citation:**
Way, M. J., A. D. Del Genio, N. Y. Kiang, L. E. Sohl, D. H. Grinspoon, I. Aleinov, M. Kelley, and T. Clune (2016), Was Venus the first habitable world of our solar system?, *Geophys. Res. Lett.*, *43*, doi:10.1002/2016GL069790.

# Was Venus the first habitable world of our solar system?

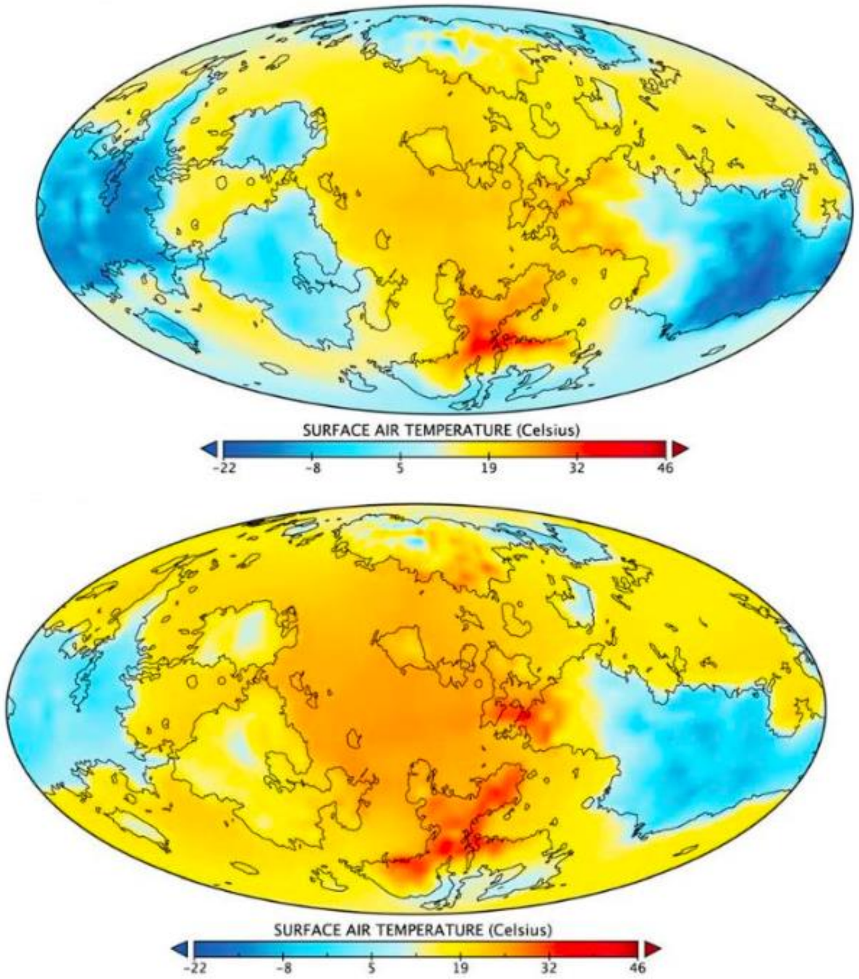
**M. J. Way[1,2], Anthony D. Del Genio[1], Nancy Y. Kiang[1], Linda E. Sohl[1,3], David H. Grinspoon[4], Igor Aleinov[1,3], Maxwell Kelley[1], and Thomas Clune[5]**

[1]NASA Goddard Institute for Space Studies, New York, New York, USA, [2]Department of Astronomy and Space Physics, Uppsala University, Uppsala, Sweden, [3]Center for Climate Systems Research, Columbia University, New York, New York, USA, [4]Planetary Science Institute, Tucson, Arizona, USA, [5]Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

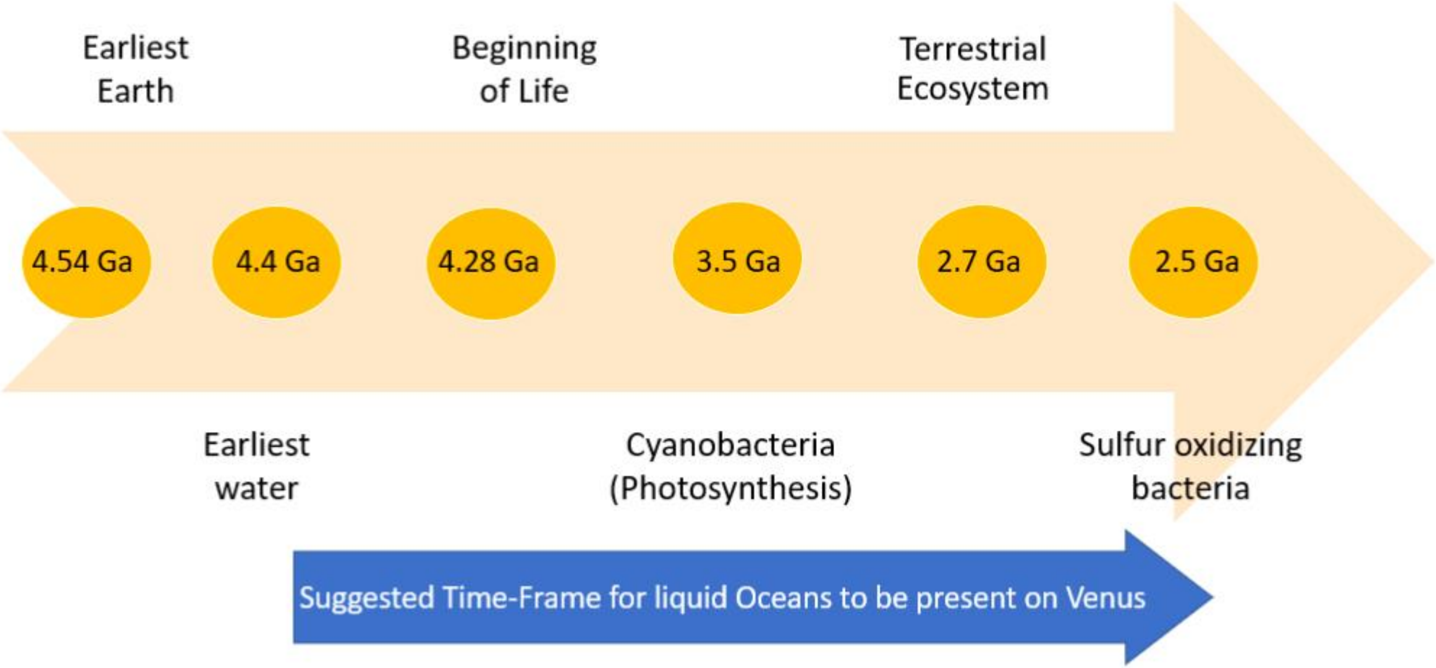
**Abstract** Present-day Venus is an inhospitable place with surface temperatures approaching 750 K and an atmosphere 90 times as thick as Earth's. Billions of years ago the picture may have been very different. We have created a suite of 3-D climate simulations using topographic data from the Magellan mission, solar spectral irradiance estimates for 2.9 and 0.715 Gya, present-day Venus orbital parameters, an ocean volume consistent with current theory, and an atmospheric composition estimated for early Venus. Using these parameters we find that such a world could have had moderate temperatures if Venus had a prograde rotation period slower than ~16 Earth days, despite an incident solar flux 46–70% higher than Earth receives. At its current rotation period, Venus's climate could have remained habitable until at least 0.715 Gya. These results demonstrate the role rotation and topography play in understanding the climatic history of Venus-like exoplanets discovered in the present epoch.

For over two billion years our solar system may have contained two neighboring terrestrial planets with habitable surface oceans.

A

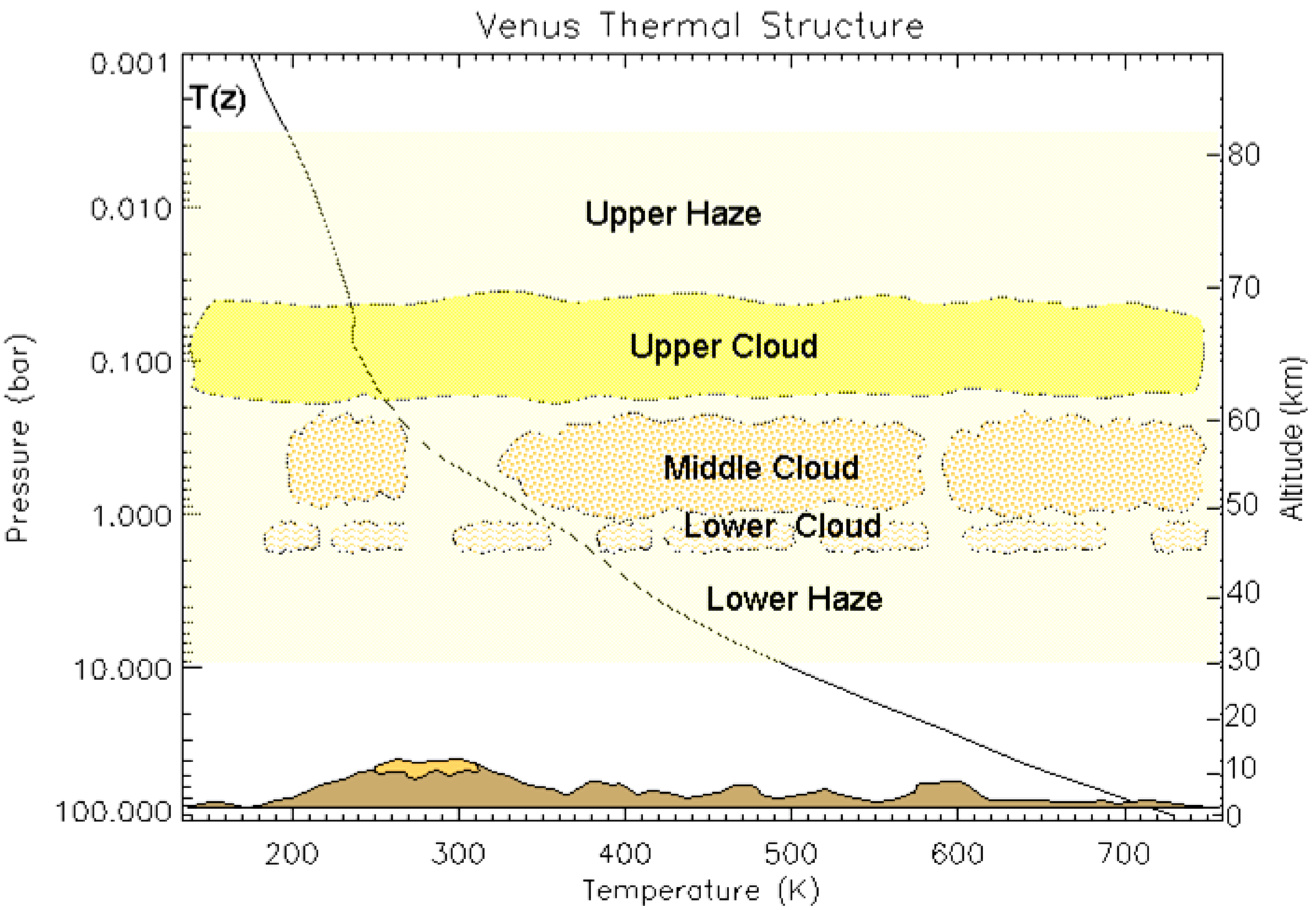



B




Way et al. 2016

Neira et al. 2018


Venus Thermal Structure
T(z)
Upper Haze
Upper Cloud
Middle Cloud
Lower Cloud
Lower Haze
Pressure (bar)
0.001
0.010
0.100
1.000
10.000
100.000
Altitude (km)
80
70
60
50
40
30
20
10
0
200
300
400
500
600
700
Temperature (K)

# The Possibility of Extant Life

- During an extended period of water loss, Venus probably enjoyed an oxygenated atmosphere.

- When young, the terrestrial planets were constantly exchanging material, thus forming a polybiosphere (a biopolysphere?)

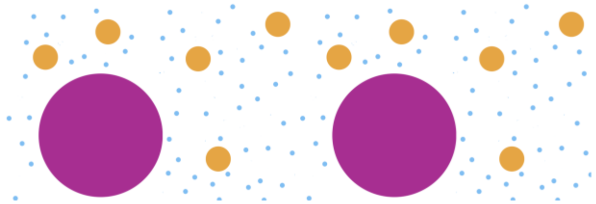
- Favorable environmental conditions for origin or transplantation of life.

- As surface conditions became hostile, could life have adapted to an atmospheric niche under directional selection?

# Properties of Venus Clouds Hospitable to Life

- Global clouds are much larger, more continuous, and stable than clouds on Earth. Particle lifetimes of months (Grinspoon et al, 1993). "Particles do not fall" (Imamura, 2006)

- Large "mode 3" particles at lower cloud level (~ 50 km altitude)
  - -- 1 bar atm pressure
  - -- ~350 K
  - -- make up most of the mass of the cloud deck
  - -- may contain an unknown, non-absorbing core material which comprises up to 50% by volume of the particles (Cimino, 1982; Grinspoon et al. 1993).

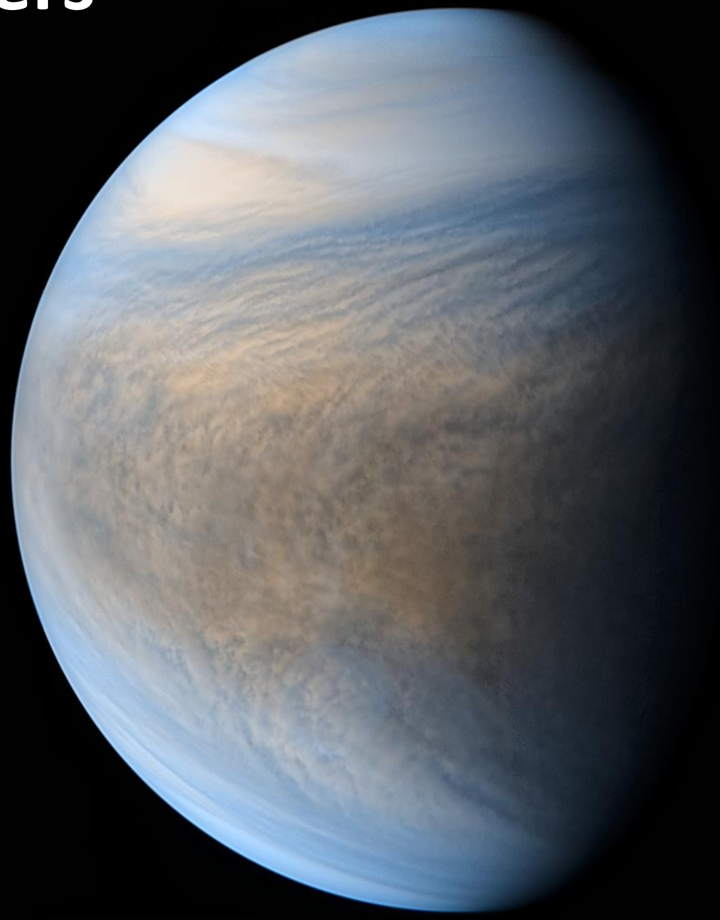


- Superrotation of atmosphere shortens duration of the night

- Chemical disequilibrium => coexistence of $H_2$ and $O_2$
  
  $H_2S$ and $SO_2$

# Unknown Ultraviolet Absorbers

- Absorb more than half the solar energy striking Venus
- Distributed in upper cloud layer
- Possible compounds of S or Cl, but no known candidate matches spectra & stability requirements.
- High temporal and spatial variability
- Has been proposed as a biological pigment (Grinspoon, 1997; Limaye et al., 2018)



# A Sulphur-Based Survival Strategy for Putative Phototrophic Life in the Venusian Atmosphere

D. Schulze-Makuch, D.H. Grinspoon, O. Abbas, L.N. Irwin & M. Bullock (2004) . *Astrobiology*, 4, 11-18.

## Abstract

Several observations indicate that the cloud deck of the Venusian atmosphere may provide a plausible refuge for microbial life (Sagan, 1961; Grinspoon, 1997; Schulze-Makuch and Irwin, 2002; Schulze-Makuch and Irwin, 2004). Having originated in a hot proto-ocean or been brought in by meteorites from Earth (or Mars), early life on Venus could have adapted to a dry, acidic atmospheric niche as the warming planet lost its oceans. The greatest obstacle for the survival of any organism in this niche may be high doses of ultraviolet (UV) radiation. Here we make the argument that such an organism may utilize sulphur allotropes present in the Venusian atmosphere, particularly $S_8$, as a UV sunscreen, as an energy converting pigment, or as a means for converting UV light to lower frequencies that can be used for photosynthesis. Thus, life could exist today in the clouds of Venus.

ASTROBIOLOGY
Volume 18, Number 10, 2018
Mary Ann Liebert, Inc.
DOI: 10.1089/ast.2017.1783

**Hypothesis Article**

# Venus' Spectral Signatures and the Potential for Life in the Clouds

Sanjay S. Limaye,[1] Rakesh Mogul,[2] David J. Smith,[3] Arif H. Ansari,[4]
Grzegorz P. Słowik,[5] and Parag Vaishampayan[6]

## Abstract

The lower cloud layer of Venus (47.5–50.5 km) is an exceptional target for exploration due to the favorable conditions for microbial life, including moderate temperatures and pressures (~60°C and 1 atm), and the presence of micron-sized sulfuric acid aerosols. Nearly a century after the ultraviolet (UV) contrasts of Venus' cloud layer were discovered with Earth-based photographs, the substances and mechanisms responsible for the changes in Venus' contrasts and albedo are still unknown. While current models include sulfur dioxide and iron chloride as the UV absorbers, the temporal and spatial changes in contrasts, and albedo, between 330 and 500 nm, remain to be fully explained. Within this context, we present a discussion regarding the potential for microorganisms to survive in Venus' lower clouds and contribute to the observed bulk spectra. In this article, we provide an overview of relevant Venus observations, compare the spectral and physical properties of Venus' clouds to terrestrial biological materials, review the potential for an iron- and sulfur-centered metabolism in the clouds, discuss conceivable mechanisms of transport from the surface toward a more habitable zone in the clouds, and identify spectral and biological experiments that could measure the habitability of Venus' clouds and terrestrial analogues. Together, our lines of reasoning suggest that particles in Venus' lower clouds contain sufficient mass balance to harbor microorganisms, water, and solutes, and potentially sufficient biomass to be detected by optical methods. As such, the comparisons presented in this article warrant further investigations into the prospect of biosignatures in Venus' clouds. Key Words: Venus—Clouds—Life—Habitability—Microorganism—Albedo—Spectroscopy—Biosignatures—Aerosol—Sulfuric Acid. Astrobiology 18, xxx–xxx.

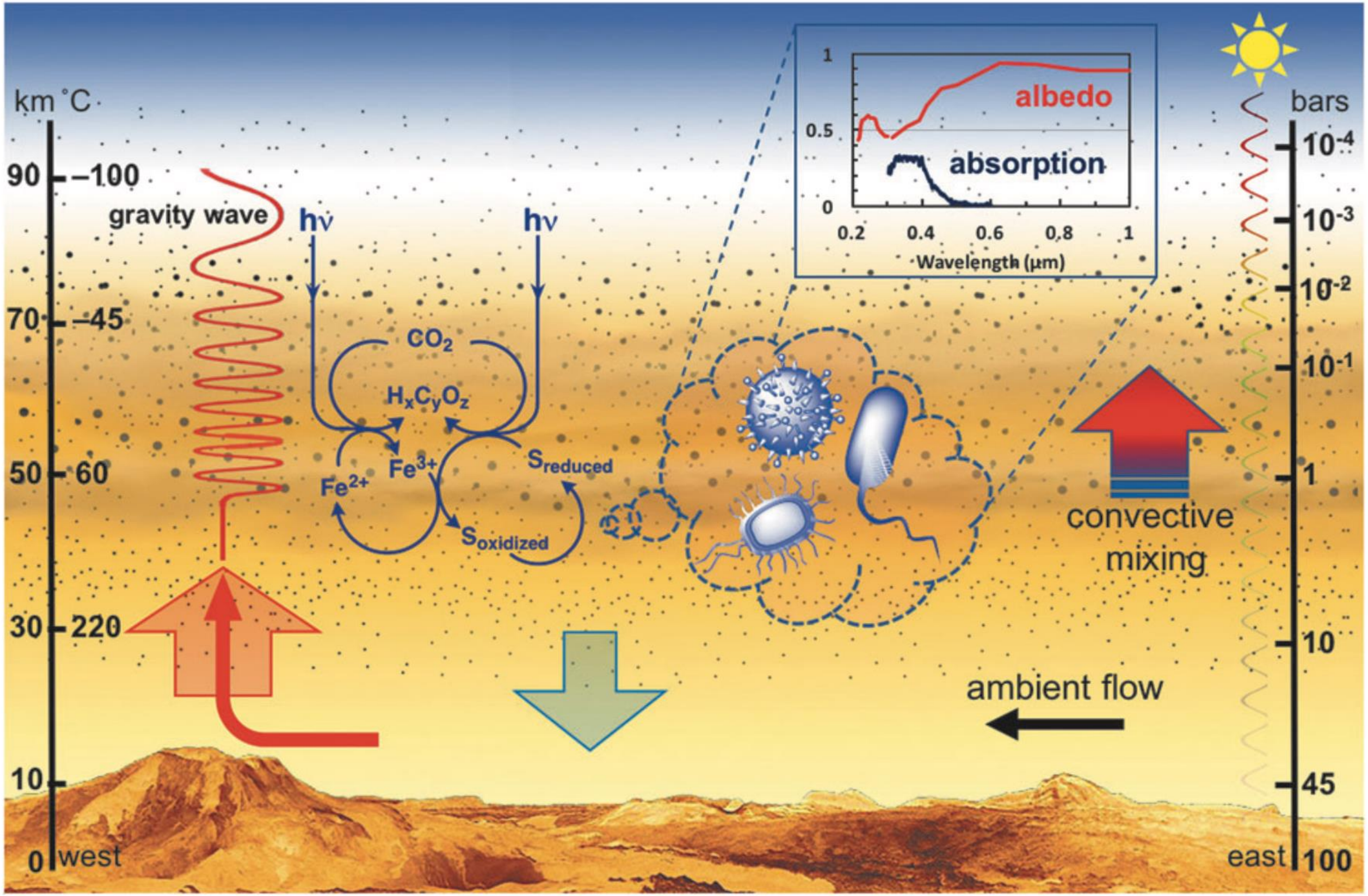



**FIG. 9.** A schematic representation summarizing the ideas presented in this hypothesis paper regarding the potential for microorganisms to survive in Venus' lower clouds and contribute to the observed bulk spectra. In this scheme, the

# Phototrophic Organisms ?

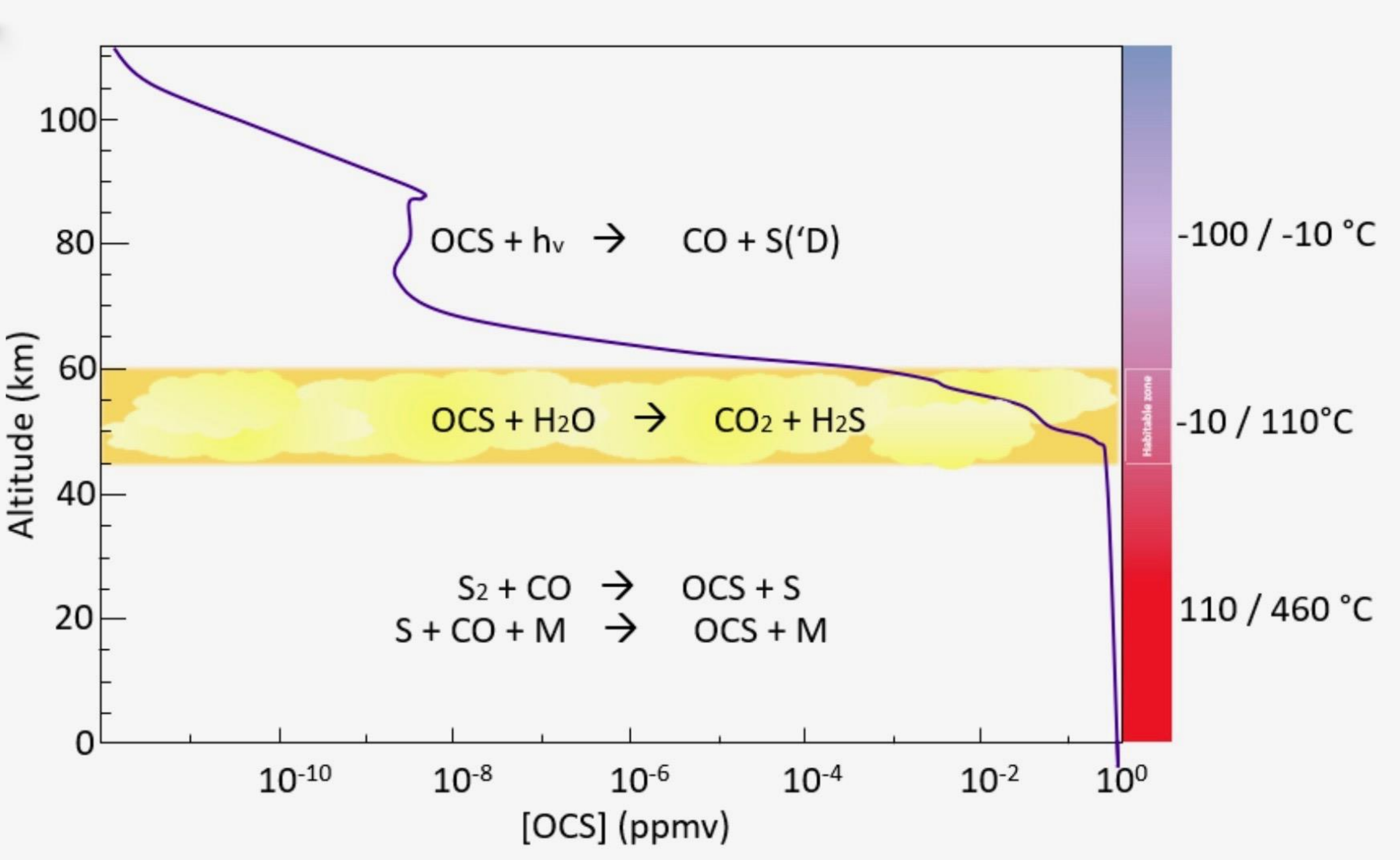
- Unknown UV absorbers detected in Venusian clouds
- Photosynthetic pathway on Venus could be associated with oxidation of $H_2S$ or COS to $SO_2$
- No known organism uses UV light as energy source (terrestrial organisms use visible or near IR light)

# Chemotrophic Organisms ?

$$H_2 + 2\,CO + SO_2 \rightarrow 2\,CO_2 + H_2S \qquad \Delta G = -248.1 \qquad (1)$$

$$3\,CO + SO_2 \rightarrow COS + 2\,CO_2 \qquad \Delta G = -246.3 \qquad (2)$$

- Both reactions could help explain low concentration of CO
- Higher concentration of $H_2S$ near cloud level could imply active reduction mechanism by chemoautotroph ( Eq. 1)
- Water is scarce, but so is $CO_2$ on Earth (assimilated from atmosphere by terrestrial microbes)

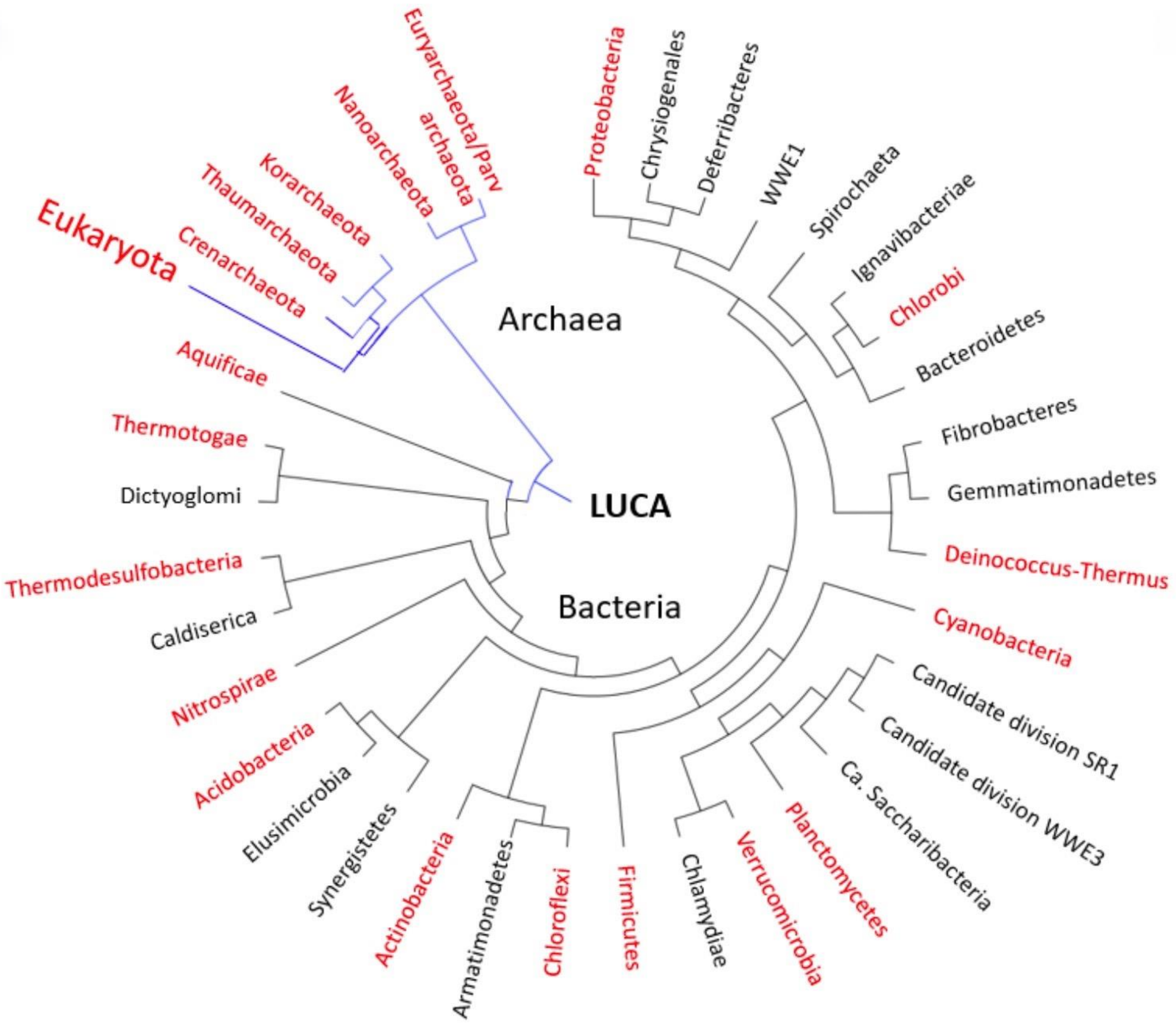



Neira et al. 2018

The low pH limit of Terrestrial life is not known.

Many organisms have now been discovered that grow at very low pH

For example, the archaeon *ferroplasma acidarmanus* thrives at pH 0.




"We posit that low pH does not represent an insurmountable challenge for life. On the contrary, life on Earth is abundant in many low pH environments even in the presence of high temperatures, low temperatures, high salt concentrations, low water activity, anaerobicity, etc. Furthermore, organisms that thrive at low pH are distributed all over the Tree of Life suggesting that the evolution of the ability to live at low pH (acidophilia) is not only plausible but rampant."

Neira et al. 2018

# Rare Planetary Properties of Astrobiological Interest

- Venus is our only other example of
  - an Earth-sized terrestrial planet.
  - a "currently active" terrestrial planet.

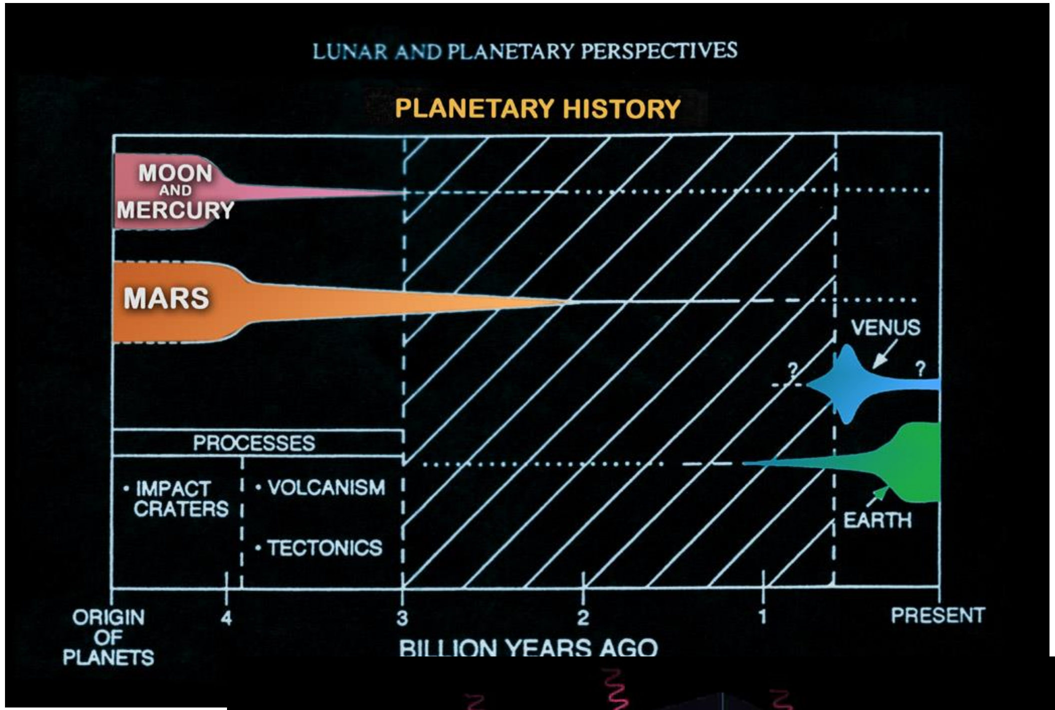
Most of surface is "young"

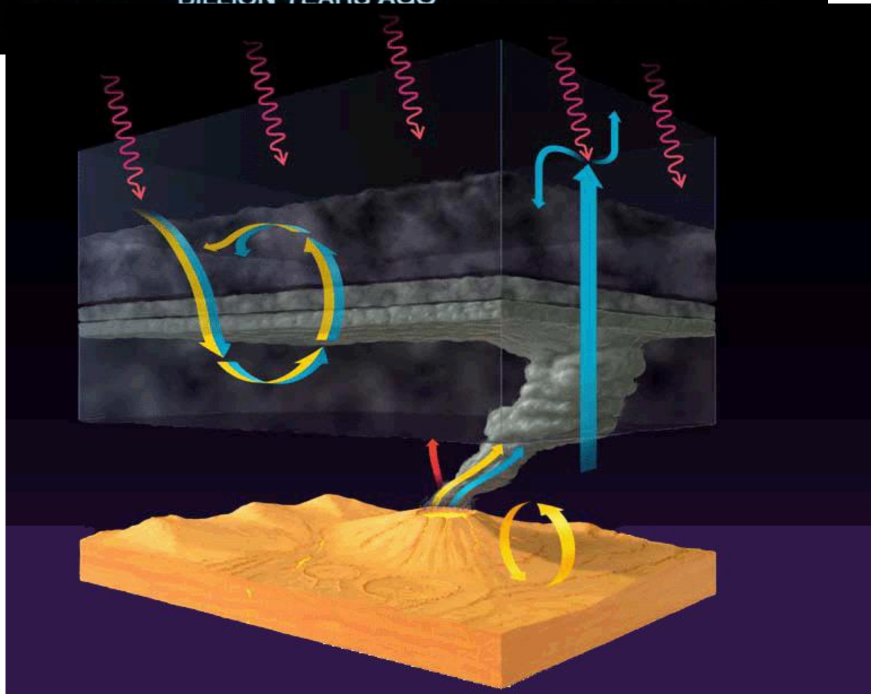
Endogenous geological activity and surface chemistry are, to some degree, controlling the atmosphere & climate

If we think beyond the specifics of a particular chemical system required to build complexity and heredity, we can ask what general properties an inhabited planet must possess. Judging from our sample of one inhabited planet, the answers might include an atmosphere with signs of flagrant chemical disequilibrium, solar driven chemical and dynamical cycles and active, internally driven cycling of volatile elements between the surface, atmosphere and interior.

**At present, the two planets we know of which possess these characteristics are Earth and Venus**.

Disequilibrium atmospheric states have emerged as the primary biosignature for exoplanets. Crucial to understand sources of disequilibrium in Venus atmosphere!



# Cloud Microbe Model

Rate of growth:

$$\frac{dn(t)}{dt} = \frac{n(t)}{\tau_B}$$

$\tau_B$ = microbial lifetime

# Cloud Microbe Model

Add fallout at bottom of cloud:

$$\frac{dn(t)}{dt} = \frac{n(t)}{\tau_B} - \frac{n(t)}{\tau_S}$$

$\tau_S$ = aerosol lifetime in cloud

# Cloud Microbe Model

Add loss due to resource limits

$$\frac{dn(t)}{dt} = \left(\frac{1}{\tau_B} - \frac{1}{\tau_S}\right) n(t) - \frac{n^2(t)}{n * \tau_B}$$

n* = Maximum number of microbes per droplet

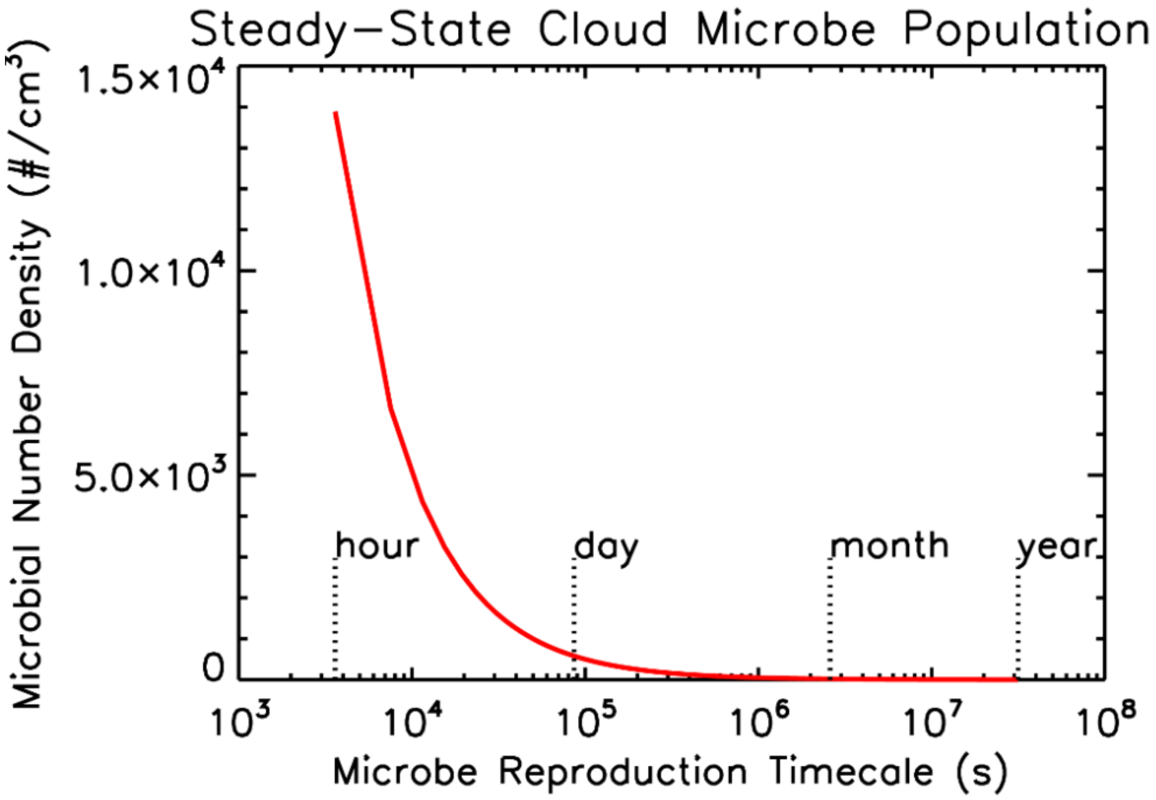
# Cloud Microbe Model

Steady state solution

$$n_{SS} = n_B^* \left(1 - \frac{\tau_B}{\tau_S}\right)$$

$n^*$ = Maximum number of microbes per droplet

# Venus Cloud Aerosol Lifetimes Compatible with Life?



"All is a woven web of guesses" – Xenophanes

All ideas about extraterrestrial biochemistry are extrapolations from a single example. This is necessary, for now, but requires humility. All conclusions as to what is "universal" must be regarded as provisional.

Resist groupthink:  some potential locales for life become more acceptable through repetition.

Its *plausible* that life exists within the ocean of an ice covered world that has never seen sunlight.
Its *plausible* that life exists underground within a planet that is largely, geologically dead.

And its *plausible* that life exists within the clouds of a planet with vibrant chemical flows, energy sources, stable aqueous environment etc.

Among the *plausible* niches for extraterrestrial life in our Solar System, the clouds of Venus are among the *most accessible* and *least well explored*.