VENUS ATMOSPHERIC CHEMISTRY AND POSSIBLE METABOLIC PATHWAYS FOR MICROBIAL ORGANISMS

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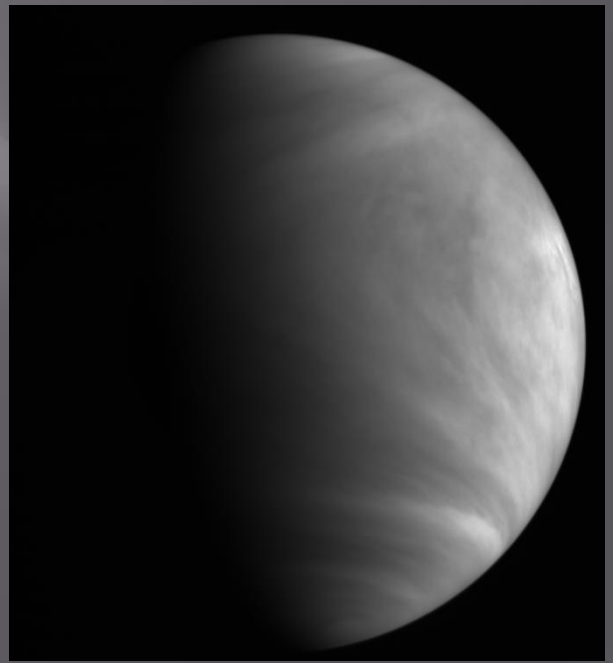
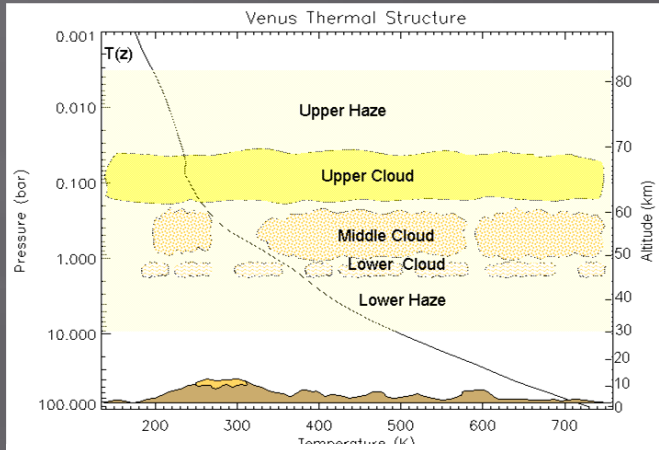
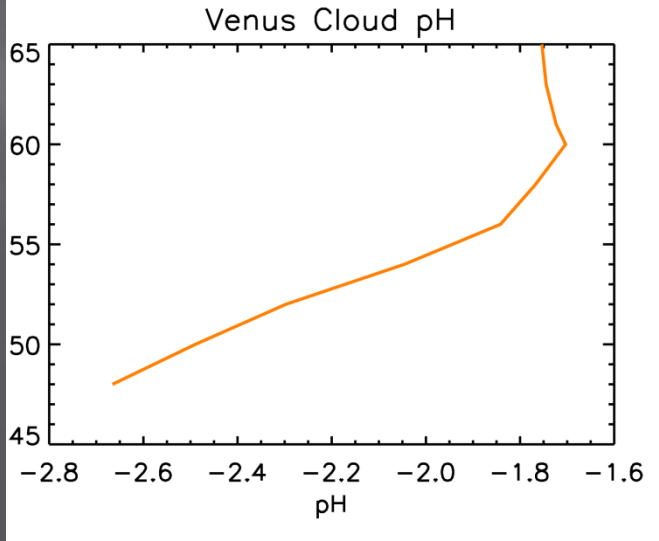


Cloud Layer Habitability Workshop
2-5 Oct, 2019 IKI RAS

Venus Cloud Characteristics

- Temperatures between -53 and 93°C
- Pressures from 30 mbars to 1.3 bars
- Liquid aerosols with radii 0.1 to 10 μm
  - Number densities from 10 to 1000 cm^{-3}
- Aerosol *p*H from -1.6 to -2.7
- Atmospheric sulfur is in forms from highly reduced to highly oxidized (H_2S - S_n- SO_4^{2-})



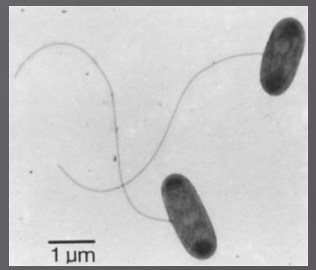


Conclusions

- The clouds of Venus represent the closest habitable niche to the Earth.
- The wide range of oxidation state of atmospheric sulfur gases:
  - Means that the atmosphere is out of chemical equilibrium
  - Provides a variety of known terrestrial microbe metabolisms to be hidden in the cloud chemistry
- Biological measurements can be accomplished by the *in situ* characterization of gas and aerosol chemistry that is necessary to understand Venus' sulfur cycles.

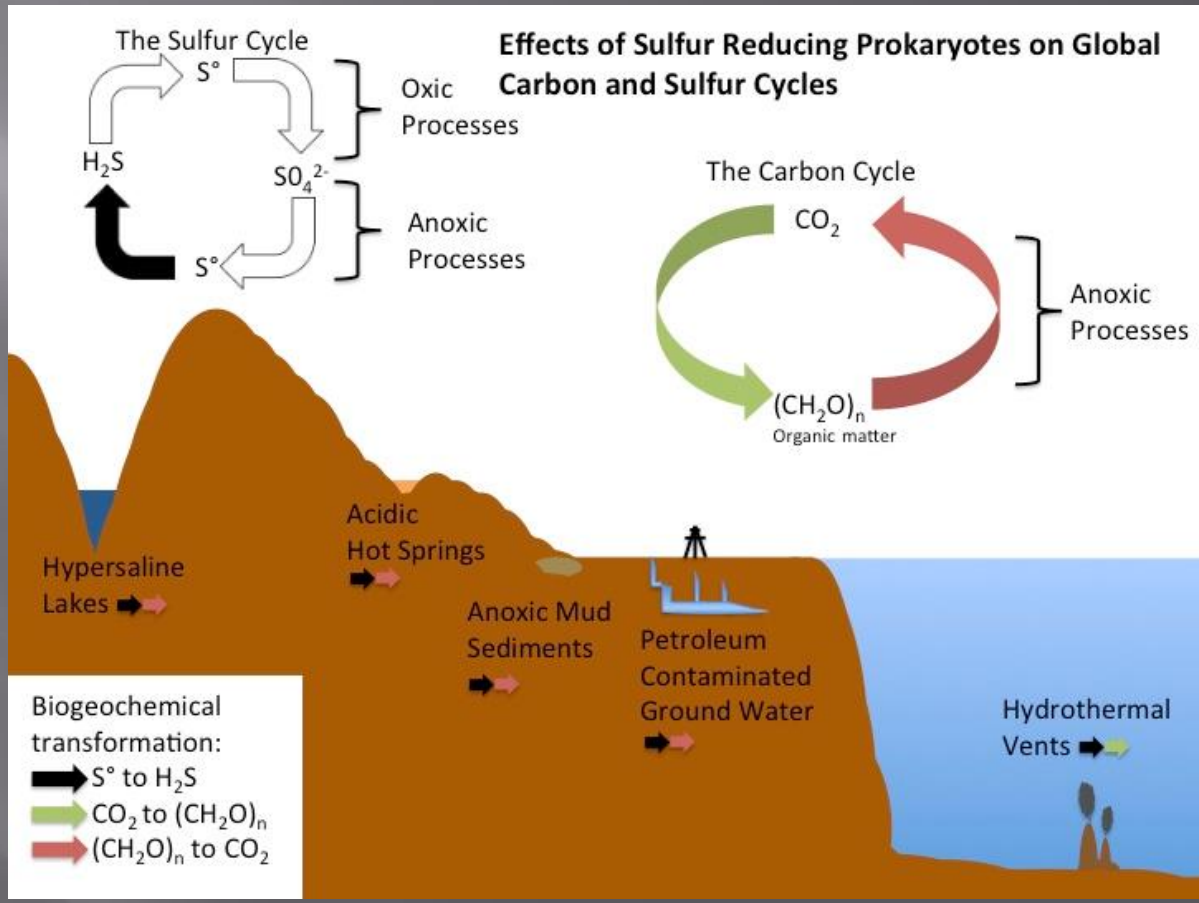
Plausible archaea and bacterial metabolisms

- Sulfur-Reducing Bacteria and Archaea (SRB)
  - Anaerobic reduction of S^0 to H_2S
  - Carbon sources: acetate, ethanol, carbon dioxide, or propionate
  - Found throughout the Earth's sulfur column
    - Acid hot springs
    - Hypersaline lakes
    - Hydrothermal vents
- Sulfate-Reducing Microorganisms (SRM)
  - Anaerobic reduction of SO_4^{2-} to H_2S
  - Some can also reduce nitrates, nitrates, fumarates, and ferric iron
  - 3.5 billion years old, influencing Earth's sulfur cycle over geologic time
  - Found in:
    - Seawater and sediments
    - Hydrothermal vents
    - Acid mine drainage sites

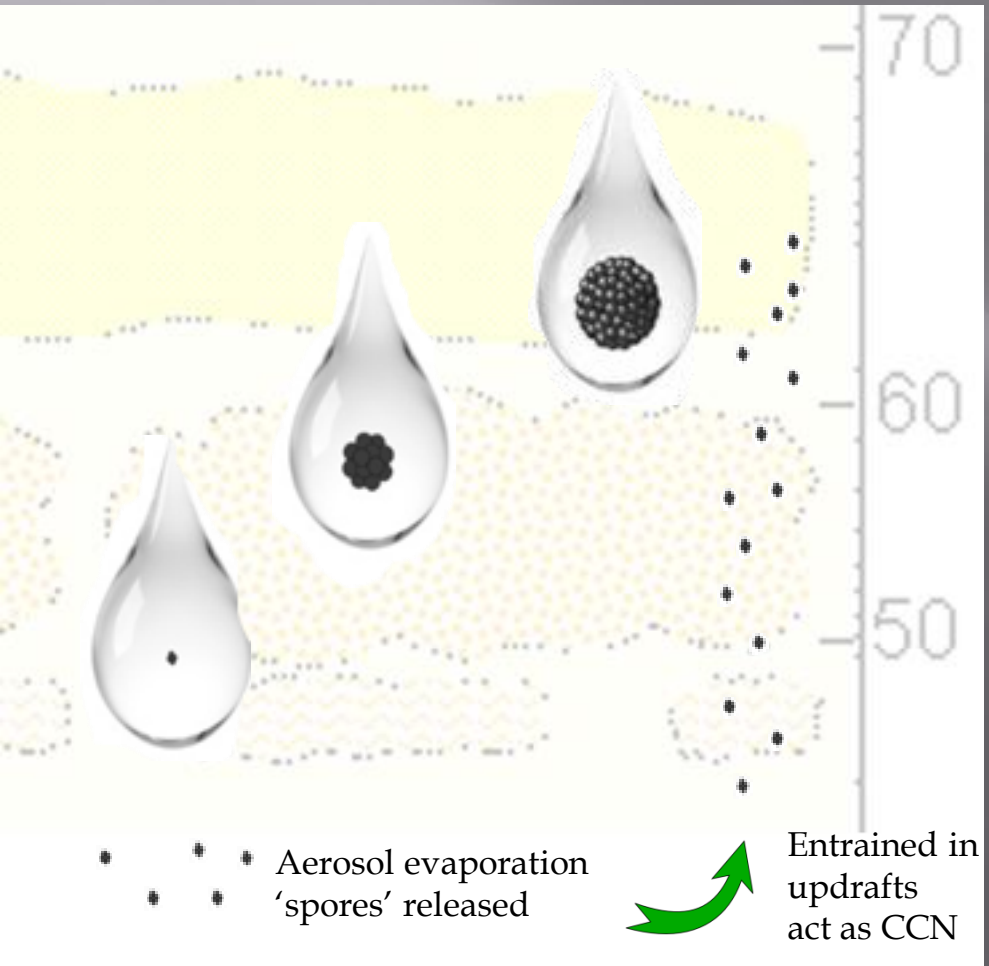


Effects of SRBs on Earth Chemical Cycles

- SRB respirate S^0 to H_2S in anoxic conditions
- CO_2 reduction provides carbon
- From Microbwiki https://microbewiki.kenyon.edu/index.php/Sulfur-Reducing_Bacteria_and_Archaea



Cloud Microbe Model



Continuity equation for microbes in aerosols

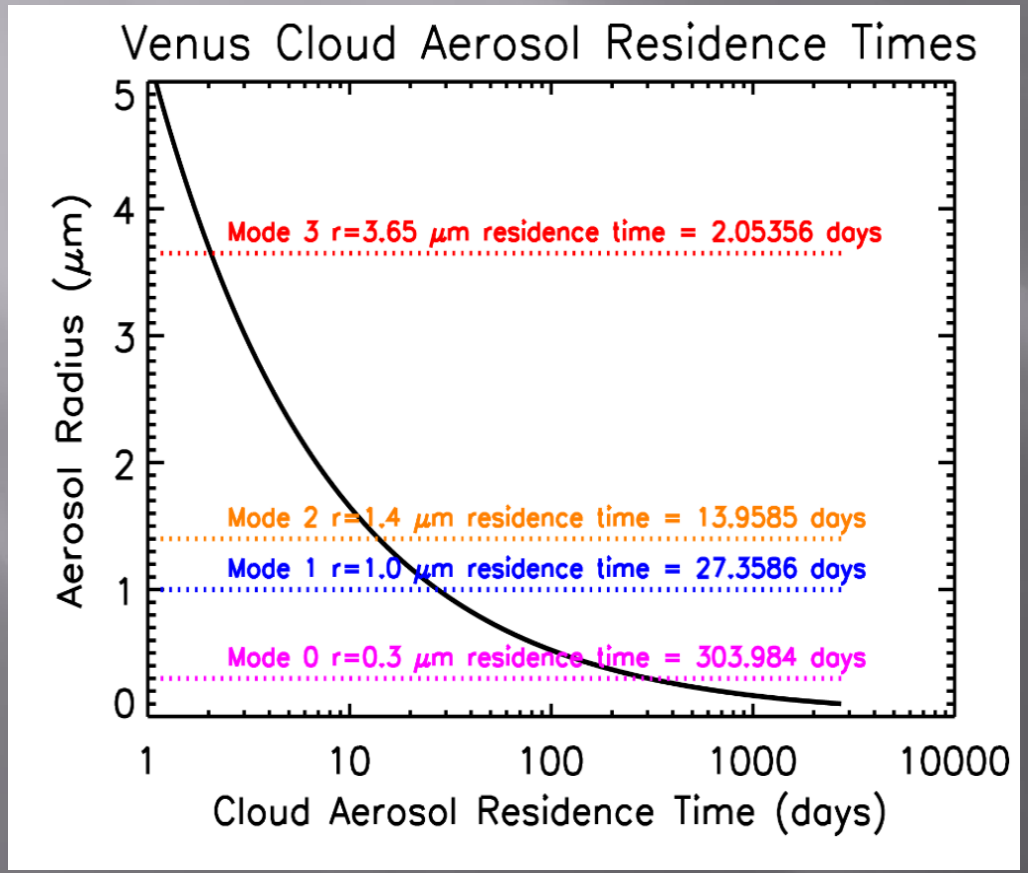
$$\frac{dn(t)}{dt} = \left(\frac{1}{\tau_B} - \frac{1}{\tau_S}\right) n(t) - \frac{n^2(t)}{n^* \tau_B}$$

τ_S = aerosol lifetime in cloud
τ_B = microbial lifetime
n* = Maximum number of microbes per droplet

Plus conservation-transport equations for atmospheric sulfur species

Requires 2 states:
Microbial colonies and 'spores' to seed other aerosols
Grinspoon, 2019, this workshop

Are Venus Cloud Aerosol Lifetimes Compatible with Life?



- Particle lifetimes 2-300 days
- Mode 2 ~14 days
- If microbial lifetime is < 14 days, they could persist in the clouds

Model calculates the growth and loss of microbes that reduce available SO_4^{2-} to S_n and H_2S

Steady state profiles for sulfur gases are altered due to microbial metabolism

Are abundances consistent with available data?

Exploration

- In order to understand the chemical constituents and chemical reactions in the clouds, in situ exploration is critical.
- Aerial vehicles such as balloons, descent probes, fixed-wing aircraft, aerobots, and rotorcraft all have the ability to undertake this mission
- In order to maximize the success of physical and chemical analysis of the clouds, it is desirable to have:
  - Long duration (> 30 days)
  - Capable payload of sensors, aerosol analyzers, microscopy, IR and Raman spectroscopy, and reliable means of collection of gases and aerosols repeatedly
  - The ability to navigate in 3 dimensions, based on measurements taken up to that time. Such a vehicle could be directed to up and down drafts, to regions with concentrations of the unknown near-UV absorber, or into gravity waves forced from the surface

VEXAG White Paper

The in situ Exploration of Venus' Clouds by Dynamic Soaring

Expanding Exploration Capabilities through Energy Harvesting

M.A. Bullock, J. Elston, M. Stachura, S. Lebonnois, S. S. Limaye, D. H. Grinspoon

Black Swift Technologies

- Long duration sustained flight through energy harvesting
- Autonomous or controlled navigation
- 10 kg of sensors and payload for the physical and chemical characterization of Venus' clouds and atmosphere