VENUS, AN ASTROBIOLOGY TARGET

SANJAY S. LIMAYE, RAKESH MOGUL, KEVIN. BAINES, MARK BULLOCK, CHARLES COCKELL, JAMES CUTTS, DIANA GENTRY, DAVID GRINSPOON, JAMES HEAD, KANDIS-LEA JESSUP, VIKTOR KOMPanichenko, YEON JOO LEE, RICHARD MATHIES, TETYANA MILOJEVIC, ROSALYN PERTZBORN, LYNN ROTHsCHILD, SATOSHI SASAKI, DIRK SCHULZE-MAKUCH, DAVID J. SMITH, MICHAEL WAY

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EARLY VENUS WAS LIKELY HABITABLE

• Presence of past water on the surface suggested by high D/H ratio compared to Earth’s mean ocean water by ~ 150 (Donahue et al., 1982)

• Modeling of past climate suggests that liquid water could have existed for as long as 2-3 billion years (Way et al., 2016; Way and DelGenio, 2020)

• Modeling the transition from mobile lid into a stagnant lid convection suggests that “Venus may have had both a mobile lid and near-surface liquid water for the first 3+ billion years of its history – Weller and Kiefer (2020)

• Over the long duration of the existence of liquid water on the surface, life could have originated on Venus or it could have been seeded from elsewhere and evolved
Measurements

- D/H ratio in the clouds compared to the sea level value for Earth ($\sim x150$)
- Almost twice as high a ratio above the clouds (Fedorova et al., 2008)

Interpretations

- Surface rock composition (Hashimoto et al. 2008; Mueller et al. 2017)
- Some of the tessera terrains are very old and may have formed in presence of water (Gilmore and Glaze 2013)

Modeling studies

- Past climate: Way et al. 2016
- Way and Del Genio (2020)
- Transition from mobile to stagnant lid tectonics - Weller and Kiefer (2020)

*If it did not have past surface liquid water, why not? Why should Venus and Earth be so different in the liquid water presence in the past?*
VENUS’ LONG HABITABILITY

Did Venus have a long period with an Earth-like climate?

Venus could have been continuously habitable for ~3 Billion years. It reached its present state by a combination of intrusive (Large Igneous Provinces) and then intrusive+extrusive volcanism (e.g. Basaltic Flats, Coronae).

It provides the needed impetus to make critical measurements at the surface of Venus to confirm this picture. If true a host of exoplanets in Venus-like orbits may be habitable and viable Earth-like targets.

Venus may have been much more like Earth than we considered possible even a few year ago.

Michael J. Way and Anthony Del Genio 2020, “Venusian Habitable Climate Scenarios: Modeling Venus through time and applications to slowly rotating Venus-Like Exoplanets,” Journal of Geophysical Research – Planets: http://dx.doi.org/10.1029/2019JE006276
WHERE COULD LIFE ON VENUS HAVE COME FROM?

- Did it originate on Venus surface in hydrothermal vents?
- Panspermia?

Did life evolve over the long duration of water presence on the surface?
Present Venus Cloud Structure from Entry Probes

- **Upper haze**
- **Upper cloud**
- **Middle & Lower cloud**
- **Lower haze**

**Aerosol extinction**

**Stability**

**UV absorber**

- **Most UV absorbed**

**Temperature (K)**

**Altitude, km**

**Surface haze**
Once conditions became inhospitable on the surface, microorganisms could have found a niche in the clouds which still remain a potential habitable zone today (Cockell, 1999)
HYPOTHESES IN THE VENUS CLOUDS

- Morowitz and Sagan (1967) – *Floating bacteria in the clouds*
- Hapke and Nelson (1975) – *Sulfur based bacteria with absorptive properties*
- Shimizu (1977) – *graphite and microorganisms responsible for UV absorption*
- Boyer (1996) – *photosynthetic microorganisms that affect the speed of the zonal flow*
- Grinspoon (1997) – *acid resistant bacteria*
- Cockell (1999) – *Venus cloud layer may be habitable*
- Schulze-Makuch and Irwin (2002) – *acid resistant bacteria*
- Limaye et al. (2018) – *microorganisms based on Fe-S chemistry may contribute to the solar energy absorption and cloud contrasts*
- Greaves et al. (2020) – *Possible detection of phosphine, may be a biosignature*
Although the present day surface conditions are extreme, the cloud layer (48-70 km) presents less hostile temperature conditions for survival of life for polyextremophiles in the acidic and low water activity zone.

Essential ingredients for life (C, H, N, O, P and S) are found in the cloud layer with other required minerals likely available for microorganisms to have survived in the clouds after the surface water was lost.

Re-analysis of Pioneer Venus Large Probe Neutral Mass Spectrometer (Hoffman et al., 1980) data suggests that additional chemical disequilibria exist within the lower cloud layer (Mogul et al., GRL, 2021) and phototrophy is possible (Mogul et al., under review, Astrobiology, 2021).
Rationale for considering Venus for Astrobiology Exploration

• The likelihood that liquid water existed on the surface for 2-3 Ga, leading to potential for origin and evolution of life under clement conditions

• Any microorganisms adapted to the changing surface habitat and migrated to the cloud layer where habitable conditions exist at present for the polyextremophiles

• Multiple chemical dis-equilibria are found in the Venus atmosphere

• How active aerobiology may impact the radiative energy balance of Venus’ clouds and Venus-like atmospheres, and

• Help assess habitability of exoplanets in the “Venus zone”
Astrobiology Goals for Venus

1. To better understand the geochemical and geological (volcanism) forces that influence radiative energy balance and cloud dynamics.

2. To better constrain the timelines framing (i) the formation of potential surface water bodies, (ii) subsequent rates of water loss to the atmosphere, and (iii) formation of stable cloud layers.

3. To obtain detailed physical, chemical, and biological characterizations of the cloud aerosols - (a) abundances of biologically relevant elements (CHNOPS and transition metals), phosphorous oxides, and low-molecular-weight chemicals within the cloud layers and fluxes, (b) abundances within the cloud layers, inclusive of vertical profiles and fluxes, (c) microscopic imaging and characterization of the aerosols, and (d) biological investigations when and if feasible.

4. To validate findings from remote spectroscopy by using terrestrial geological, atmospheric, geochemical, biochemical, and photochemical–biological experimental models.

5. To validate the findings on trace species abundances from remote observations and modeling by spatially distributed in situ measurements at different local times, from at least 70 km down to the surface.
Need to go back to Venus to find out:

- Nature and identity of absorbers – *chemical or biological*?
- Chemical composition (minor and *trace/disequilibrium species*) of the atmosphere
- Aerosols – chemical composition, physical, optical and biological properties
- Evolution of Venus spectral albedo and contrasts over time – *radiative balance*
- Determination of *past presence of water* on the surface via surface mapping with mineralogical properties
- Photochemical models that include *biology*
- Laboratory Measurements under simulated cloud conditions of candidate terrestrial microorganism properties to interpret measurements
Questions

- What is the composition of the cloud droplets – are there other substances present besides H$_2$SO$_4$ and H$_2$O?

- What are the abundances of the trace species in the atmosphere/cloud layer – CH$_4$, NH$_3$, PH$_3$, S, salts?

- What is the vertical gradient in the abundance of Nitrogen below 100 km?

- What is the nature and identity of the absorbers of sunlight in the atmosphere/clouds?

- What is the impact of supercritical mixture of carbon dioxide, nitrogen near the surface? Even SO$_2$ is supercritical near the surface.
| Venus astrobiology goal | Venus astrobiology objective (VAO) | Venus astrobiology investigation | Measurements/ modeling/theory | VEXAG investigations | VEXAG objective | VEXAG goal |
|------------------------|---------------------------------|--------------------------------|-------------------------------|---------------------|----------------|------------|
| Did life begin on Venus in the surface ocean in the past? | VAO.I.A. How long did liquid water ocean last? | Characterization of exposed ancient terrains by radar and mineralogy | I.A. HQ, III.A.GH, III.A.GA, I.A.RE | I.A. Did Venus have temperate surface conditions and liquid water at early times? | III.A. What geologic processes have shaped the surface of Venus? | I. Understand Venus’ early evolution and potential habitability to constrain the evolution of Venus-like (exo)planets. III. Understand the geologic history preserved on the surface of Venus and the present-day couplings between the surface and atmosphere. |
| Is the Venus cloud layer habitable today? | VAO.I.B. When did it become inhospitable on the surface by losing its liquid water ocean? | Climate Modeling | | | | |
| | VAO.II.A. What are the chemical and physical conditions with respect to life in the present-day Venus atmosphere? | Isotopic abundance profiles of noble gases and other biologically significant elements, climate models | | II.L.B. How do the atmosphere and surface of Venus interact? | II. Understand atmospheric dynamics and composition on Venus. III. Understand the geologic history preserved on the surface of Venus and the present-day couplings between the surface and atmosphere. |
| | VAO.II.B. What are the global abundances of the essential bioavailable nutrients (CHNOPS) | Accurate estimates of the atmospheric composition from in situ measurements below 70 km at representative latitudes and local solar times | | | | |
| | VAO.II.C. What other elements are bioavailable in the Venus atmosphere (trace species)? | | | | | |
| | VAO.II.D. What are the physical, spectral, and chemical properties of the cloud particles? | In situ measurements of the cloud particles at different local solar times and representative latitudes | | | | |
| | VAO.II.E. What chemical disequilibrium exist in the Venus atmosphere? | Vertical profiles of trace species in the atmosphere (0-70 km) | | III.B.CI, III.B.LW, III.B.GW | | |
| Is there life in clouds of Venus today? | III. Are there signs of biogenic activity? | If there are microorganisms in the cloud layer, are they absorbing solar radiation? | Spectral and optical properties of the microorganisms | I.I.B.RB | II.L.B. What processes determine the baseline and variations in Venus atmospheric composition and global and local radiative balance? | |
| | | What would be the theoretical biomass if the clouds could support life? | Modeling/theory | | | |

AE = Aerosols; GA = Geologic Activity; GC = Geochemistry; GH = Geologic History; HO = Hydrosis Origins; OG = Outgassing; RE = Recycling.
POTENTIAL VENUS MISSIONS IN THE COMING DECADE

• 2020 – BepiColombo Fly-by#1 of Venus next week (Closest approach on 15 October 2020)
• 2021 – BepiColombo Fly-by#2 of Venus (Closest approach on 10 August 2021)
• 2025 – Venus Orbiter Mission (Indian Space Research Organisation)
• 2025 – Akatsuki-2 if approved by JAXA
• 2026 – If selected, DAVINCI+ and/or VERITAS (NASA Discovery missions under consideration)
• 2029 – Venera-D (Russia-US collaboration)
• 2031 – EnVision if selected by ESA in the Cosmic Vision Program

Beyond 2031 – Venera sample return missions

Rocket Lab and Breakthrough Initiative Foundation have announced missions to Venus during (2023, 2024) – studies underway
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Thank you

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