Habitability Timeline of Venus: Past and Present

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Abstract

Venus is commonly known as the beautiful Evening Star of the night sky. Despite its bulk composition and size being similar (Interior ESI 0.98) to those of Earth, Venus is an extremely hot and dry planet, with temperatures ranging from 630 - 740K. With the current physical conditions, a potential areal biosphere could exist on the sulphuric acid-dominated clouds, providing moderate temperatures and pressures due to high altitudes. A theorised Iron or Sulphur metabolism could support exotic life in these extremely acidic (pH 0) conditions. The past habitability for regular life could be connected to the present habitability for exotic life through possible evolution, extending the possible Habitability timeline. Due to its smaller orbital distance (0.7 AU), Venus could have been the first habitable planet in the solar system, with optimistic models showing that Venus may have had a complex atmosphere and a liquid ocean for around 2 billion years, before the moist runaway greenhouse effect transformed the planet. High values for the D/H ratio and carbon abundance, combined with Venus's slow rotation rate indicate the potential for biological life developing in Past Venus's possible Earth-like conditions. These models were analysed from a perspective of Habitability, along with probable evolution into the present exotic life.

Habitability Timeline of Venus: Present and Past

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Overview

Venus is commonly known as the beautiful Evening Star of the night sky. Despite its bulk composition and size being similar (ESI_{int} 0.98**) to those of Earth, Venus is an extremely hot and dry planet, with temperatures ranging from 630 - 740K. With the current physical conditions, a potential areal biosphere could exist on the sulphuric acid-dominated clouds, providing moderate temperatures and pressures due to high altitudes. A theorised Iron or Sulphur metabolism could support exotic life in these extremely acidic (pH 0) conditions. The past habitability for regular life could be connected to the present habitability for exotic life through possible evolution, extending the possible Habitability timeline.

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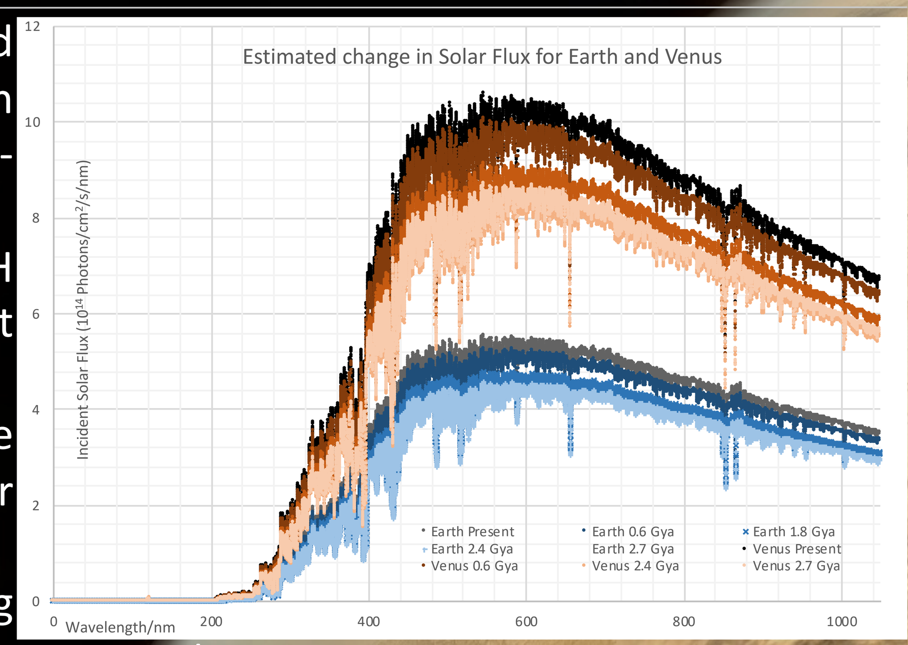
Planetary Evolution from the Past



- The close proximity to Earth and lower average solar insolation suggest that Venus was more Earth-like in the past
- Presently, Venus has a High D/H ratio (2.5×10^{-2}), suggesting that it had surface water in the past.
- The moist runaway greenhouse effect was caused by rising water vapour and CO_2 levels.
- Water was degassed due to strong solar flux in the ionizing spectrum, rising CO_2/H_2O ratio, and high temperatures. Following this, Hydrogen was removed through thermal and non-thermal processes.
- (Esposito, 1984) proposed that SO_2 was injected into Venus upper atmosphere by active volcanism, while other sulphurous gases and H_2SO_4 were produced photochemically, above the clouds.
- Venus was recently resurfaced (0.3 – 1 Gya), so its past topography and geological history are unknown.
- Oxygen may have been present in abundance in the past, enough to create a stratospheric Ozone layer, thereby protecting possible life from the UV spectrum.

Evaluation

This timeline of ≈2.9 – 0.715 Gya depends on the condition that Venus's initial rotation period was not significantly shorter than its current near tidally-locked state. There is no sustainable theory supporting life on Current Venus's surface yet.

(Bullock and Grinspoon, 2000) proposed that non-acidophilic life is likely to have developed on Venus during the early stages of its lifetime, when the average surface temperatures may have been favourable. To cope with high temperatures and low water availability on the surface, the life could have receded to the layers of the atmosphere, while adapting to the changing environment. Microbial evolution would have occurred due to the following selection pressures –

- Low water availability
- Rising UV Radiation levels
- Low pH

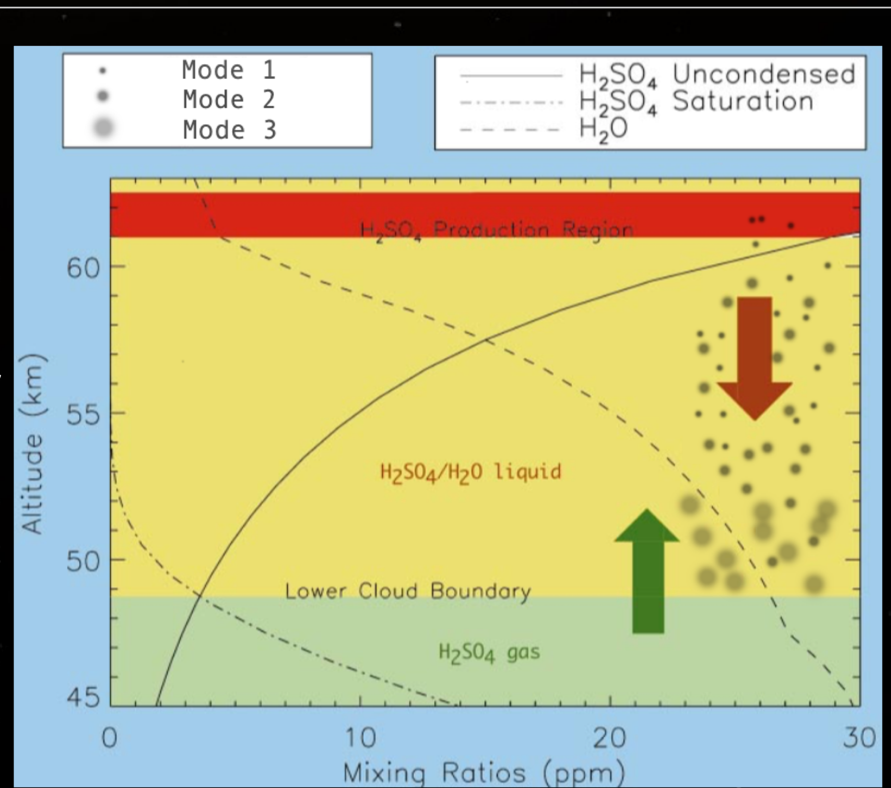
The high H_2O mixing ratios of the models suggest that Venus's massive climate change might have been caused by some external factor, for this timeline to hold true. This factor could be related Venus's abnormal obliquity, possibly a large-scale impact event, aggravating volcanism, thereby outgassing water and destabilising the surface. A possible "moon" impact of about 4.86×10^{24} g in the past could have altered a Venus with prograde rotation period of 30 days to its present state. This may have also knocked Venus from a different orbit.

The habitability timeline could be extended to more recent times, with the possibility that life evolved and survived through this rough planetary transition.

Next Steps – Working Backward, what are the conditions that transform an Earth-like Venus into present Venus at different time instances (4 Gya, 3 Gya, Present), or Earth into a Venus-like planet from the present?

The Case for Present Venus

ESI_{surf} : 0.20** ESI_{glob} : 0.44**
PHI : 0.37 BCI : 0



CO_2 (96.5%), SO_2 (150 ppm), and N_2 (3.5%) are the main components of Venus's atmosphere, while the surface is rich in silicates, Iron and Nickel. Venus's obliquity (178°), slow rotation rate (243 days), and greenhouse "heat trap" contribute towards stabilising surface and atmospheric temperature (630 – 770K).

The abundance of Carbon on Venus's surface and in the atmosphere increases the probability of finding organic molecules in its environment. The absence of global tectonics makes the possibility of surface and subsurface life unlikely.

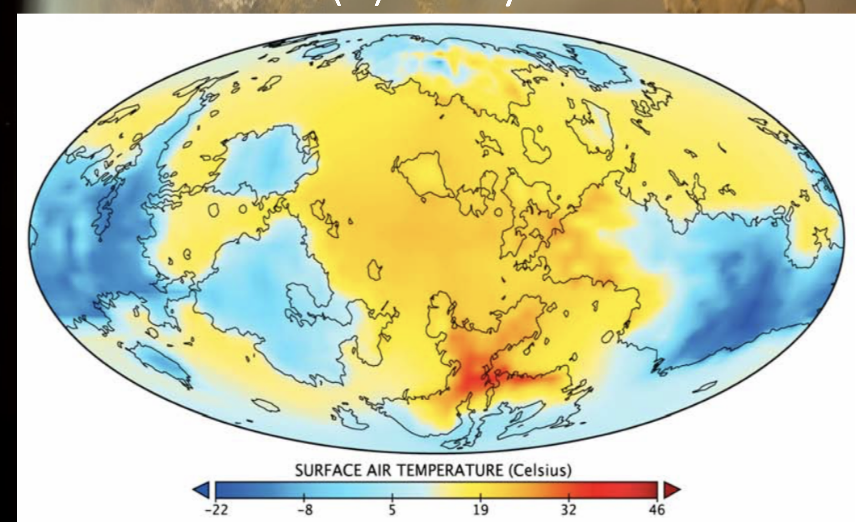
However, the Venusian clouds (48 – 60km) could support exotic life with an Iron or Sulphur metabolism, due to moderate temperatures (0 – 60°C) and pressures (0.4 – 2atm). While water is almost non-present on the surface, observations indicate that water vapour constitutes ≈15% of upper and middle clouds. The clouds are dominated (≈80%) by sulphuric acid aerosols, whose droplet size ranges from 0.2 - 8 mm, classified into 3 modes (≈0.4-0.6 μm, ≈2-2.8 μm, 7.3-8 μm). (Limaye *et al.*, 2018) predict that majority of the biomass must be found on the lower clouds due to a higher proportion of cloud columnar mass and larger average droplet size (≈2-8 μm). The acidophilic life is believed to utilise Sulphur-containing Fe proteins (Iron-sulphur clusters) for respiration, as seen on Earth.

Apart from sulphuric acid, $FeCl_3$ and S_8, observations indicate the presence of an unidentified UV absorber in the Venusian atmosphere. (Grinspoon, 1997) theorised that this UV absorber may be the microbial organisms themselves, with UV-absorbing pigments and the quick repair of damaged UV sensitive proteins, while possibly adapted to utilise this energy for photosynthetic reactions.

**Values borrowed from (Schulze-Makuch *et al.*, 2011)

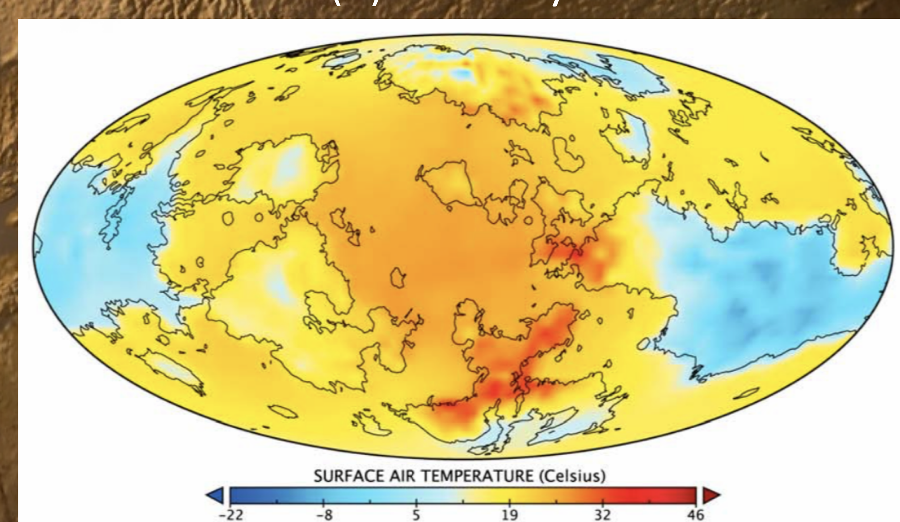
Analysing Models of Past Venus

(A) 2.9 Gya



Solar flux : 1.46 (Present Earth)
0.77 (Present Venus)
T_{min}: -22 C | T_{av}: 11 C | T_{max}: 36 C
H_2O mixing ratio ≈ 10%
ESI_{surf}: 0.95 ESI_{glob}: 0.96*
BCI: 1.47 PHI: 0.66

(B) 0.715 Gya



Solar flux : 1.70 (Present Earth)
0.94 (Present Venus)
T_{min}: -17 C | T_{av}: 15 C | T_{max}: 35 C
H_2O mixing ratio ≈ 1%
ESI_{surf}: 0.95 ESI_{glob}: 0.96*
BCI: 1.77 PHI: 0.66

*Assuming radius and density do not change over time

Conditions for models to be possible and Habitable –

- Venus retained most of its surface water throughout the early magma ocean (early Venus), or gained significant water during the late accretion.
- Venus initially had a magnetic field and plate tectonics, which declined over time, possibly due to increasing temperatures.
- Venus's primordial rotation period was above 16 days.
- Solid silicate rocks and a potential Urey atmosphere were present on Venus.

These models currently represent a potentially habitable Past Venus. They have narrower ranges of temperatures than those of Earth due to global convection currents and efficient dynamical heat transfer to the poles. Venus's denser atmosphere than Earth results in a weaker day/night circulation, due to less thermal radiation. The models and the current D/H ratio allow the presence of an ocean with volume ≈ 10^{17} m^3 (Earth's ≈ 10^{18} m^3). The current topography of Venus limits surface evaporation, thereby reducing surface humidity and the greenhouse effect at low altitudes. The models have low temperatures given their relative solar fluxes due to the cloud-albedo feedback (Bullock and Grinspoon, 2003). The slow rotation rate allows significant cloud cover, possibly covering the entire dayside for several months. T_{max} of (B) is lesser due to a greater cloud cover and albedo. A "cold trap" is not created in the nightside due to efficient heat transfer. However, several millimetres of snow could accumulate, even perennially in the high altitude and polar regions. Due to the relatively high mean temperatures and the convergence of convection currents in the equatorial region, strong precipitation would occur. Hence, detecting signs of erosion and weathering in this region would confirm that Venus had a complex atmosphere and complex atmospheric and geochemical processes. The models have low relative PHI values as there is no clear indication of biomarkers on Venus. The normalised BCI values to Earth for (A) and (B) are 0.78 and 0.94 respectively.

Acknowledgements: Image Credit: NASA/JPL-Caltech/T. Pyle, NASA/ JPL; Past Venus models from (Way *et al.*, 2016), Mixing ratio graph adapted from (Bullock,Mark and David Grinspoon, 2000), Solar flux model derived from (Claire *et al.*, 2012);

References: Chassefière *et al.*, 2011; Walker, James, 1974; Arkani-Hamed, J. and Toksöz, M.N., 1984 ; Arkani-Hamed, Jafar, 1994; Bullock,Mark and David Grinspoon, 2000; Donahue, T.M. and R.R Hodges Jr, 1992; Phillips *et al.*, 1981; Kasting, James, 1987; Singer, S.F., 1970; Basilevsky, Alexander and George McGill, 2007j; Svedhem *et al.*, 2007; Way *et al.* 2016; Barnes, *et al.* 2016; Benner *et al.* 2004; Cockell, Charles, 1999; Schulze-Makuch *et al.*, 2004; Krasnopolsky and A. Vladmir, 1986; Limaye *et al.*, 2018; Johnson, Natasha and Bruce Fegley Jr, 2000; Fegley, Burce, Jr and Allan Treiman, 1992; Luhmann, J. G. and S. J. Bauer, 1992; EcElroy *et al.*, 1982; Claire *et al.* 2012; Schulze-Makuch *et al.*, 2011; Irwin *et al.* 2014; Salvador *et al.* 2017; Pollack *et al.* 1980; von Liebig, J, 1827; Chameides *et al.*, 1979; Mvondo *et al.*, 2001; Grinspoon, D. H., 1997; Bullock,Mark and David Grinspoon, 2003; Goldblatt and Watson, 2012, Kasting *et al.*, 1984; Kasting, James, 1987;