HABITABILTY CHALLENGES IN THE VENUSIAN CLOUDS D. Schulze-Makuch[1,2], [1]Technical University Berlin, Astrobiology Group, ZAA, Hardenbergstr. 36, 10623 Berlin, Germany, schulze-makuch@tu-berlin.de, [2]School of the Environment, Washington State University, Pullman, WA 99164, USA

Introduction: The claimed detection of phosphine in the Venusian atmosphere [1] reignited the discussion about possible life at Venus. While many in the scientific community are convinced that the environmental conditions are too harsh for life to exist [e.g., 2,3], others point to the assertion that early Venus was habitable and that microbial life on Venus could have adapted to the currently extreme conditions by natural selection [e.g., 4,5]. There are several arguments in favor for possible life in the Venusian clouds. They include (1) habitable temperatures and pressures that exist in a continuous, stable cloud environment, (2) sufficiently available energy making photosynthesis in the clouds possible as a metabolic strategy, (3) life could have evolved from an early surface habitat (ocean) to a cloud habitat, (4) critical elements such as C,N,S and P are thought to be available in the atmosphere [6], and (5) prevailing disequilibrium conditions in the Venusian clouds [7], especially in regard to hydrogen [5] and nitrogen [8], which is a basic requirement for life. There are also several arguments against possible life in the Venusian atmosphere, which include (1) the extremely low water activity that appears to require unknown biochemical pathways to overcome, (2) sulfuric acid concentrations are extrapolated to be in a range that life on Earth could not cope with, and (3) the likely lack of trace metals and hydrogen [6]. The claimed detection of phosphine, a biomarker in an oxidizing environment such as the Venusian clouds [9], might be an argument in favor of life, if it can be confirmed. A thorough analysis by Baines et al. [10] resulted in no plausible abiotic pathways. However, the presence of two potentially abiotic pathways for phosphine production has recently been claimed by Omran et al. (phosphine deriving from reduced phosphorous compounds in the sub-cloud layer or from the corrosion of large impactors as they ablate near the Venusian cloud layer) [11].

Possible Solutions to Habitability Challenges at Venus. It is unquestionable that the Venusian cloud environment poses stark challenges to habitability. Could those challenges be overcome? The two main challenges are the low water activity and the extremely acidic environment. There have been made several suggestions how these challenges could be overcome. One of these is that aerosols may be cells coated by elemental sulfur [4]. Elemental sulfur is not wetted by sulfuric acid and if microbial cells exist in the Venusian atmosphere, they may not be fully enveloped and only adhere to sulfuric acid droplets. This would potentially lower the stress caused by water activity and acidity on any microorganism in that type of environment [12]. An elemental sulfur coating would also absorb UV irradiation, re-radiate these wavelengths into visible frequencies usable for photosynthesis, and thus could be the base of a primitive ecosystems based on phototrophy [4]. However, Seager et al. [13] pointed out that any putative cells would also have to be coated by hydrophilic filaments to take up critical liquids.

Another way how to reduce the acidity stress in the lower Venusian atmosphere has been suggested by Rimmer et al. [14]. They suggested that hydrogen delivered in form of aerosols, salt, or metals, which is thought to be brought up in the form of dust from the Venusian surface, could buffer the pH of the clouds to 1-2. A pH-value in this range is well within the capability of acidophilic microbes on Earth to handle. Of particular interest in this regard are hydroxide salts because their presence may also explain the depletion of sulfur dioxide in the clouds [14].

Habitability Questions that Need to be Answered. Given the claimed controversial detection of phosphine, one of the first questions to be answered is whether the phosphine detection is real [1] or whether perhaps SO_2 was misidentified as phosphine [15]. To test, we should try to detect phosphine in the infrared range and confirming it by LNMS mass spectra as done by Mogul et al. [9]. We should also search for diphosphine, because it would be an expected intermediate in the photolysis reaction of phosphine to phosphorus and hydrogen.

Another step is to investigate what kind of mechanisms could be envisioned as an adaptation to hyperacidity and extreme lack of liquid water. For example, in some hyperarid environments on Earth, life can obtain all of its needed water through deliquescence [16]. Could there be a similar "trick" to meet the challenge of living in an hyperarid environment like the Venusian atmosphere? A major challenge is that by Earth standards any organism thriving in the Venusian clouds would have to be a polyextremophile. The tolerance to extreme individual parameters such as water activity, temperature or acidity is much less in polyextremophilic microbes than in microorganisms that have only to deal with one extreme parameter. Therefore, it is questionable whether the environmental challenges in the clouds can be overcome with the biochemical repertoire that is available for Earth organisms. And we should not forget that being airborne is an additional challenge.

On the other hand, from our own planet we know that there are often surprising solutions of how life can still sustain itself in a seemingly hostile environment. One of them is to thrive in microenvironments that may be dramatically different in regard to environmental conditions than the larger-scale environment [5]. As an example, in a liquid asphalt lake the measured water activity was determined to be 0.49, well below the threshold that would allow life [17]. Nevertheless, life was present in microdroplets of water within the oil matrix [18], with the microdroplets having a much higher water activity.

Another option of how life deals with hostile conditions is that it becomes dormant for a while and then thrives again when environmental conditions become more benign. One example is that lichen under Martian radiation sheltered niche conditions metabolized despite water activity being below the known threshold for life most of the time [6, 19]. The conclusion was that the relatively short periods during the simulated sunrise and sunset with high water activities were sufficient to allow metabolism and even growth. Time frames are not restricted to daily cycles but can be vastly expanded as can be observed with seasonal changes on our planet, for example shown in tree rings - when tree growth occurs during the growing season. The dormancy phases may even stretch thousands or perhaps millions of years [20], particularly if the dormant phase occurs in spores, which are resistant to many environmental extremes. Spores have also been proposed to possibly exist in the Venusian atmosphere [13].

While there is no organism on Earth that could live in the Venusian clouds, that may not mean that possible adaptation mechanisms cannot exist. Hyperacidic low-water activity environments are rare on Earth, and there may have not been enough selection pressure on Earth to develop adaptations to these conditions.

Complimentary to the proposed theoretical work, laboratory experiments should be conducted to test selected acidophilic microorganisms on their limit to sulfuric acid concentrations. Can this limit be enhanced from generation to generation as was shown for the gradual adaptation of microbes to perchlorates [21]? Trace metals are critical for life on our planet as well. How could putative life at Venus compensate for the lack of important trace metals? Laboratory experiments to find out should ideally be conducted in very acidic environments. This is not only important for possible life on Venus but would also be useful information when exploring other extraterrestrial locations.

Upcoming Missions: Three missions to Venus have been approved, two by NASA (DAVINCI+ and VERITAS) and one by ESA (EnVision), and these missions are well-suited to find answers to some critical questions, especially how Venus became the planet it is today. The major astrobiology objectives in regard to Venus have recently been summarized by Limaye et al [5]: I. Was Venus habitable in the past? II. What are the chemical and physical conditions with respect to life in the present-day Venus atmosphere? and III. Are there signs of biogenic activity? Measurements taken by the new missions will help us gain insights on these questions. Particularly important will also be whether Venus had plate tectonics during its natural history and whether there are still active volcanoes on Venus today that may release water vapor and improve habitability conditions. The CUVIS instrument on DAVINCI+ may be especially important by revealing the nature of the still unknown UV absorber, which absorbs up to 50% of solar energy.

These missions will improve our knowledge of the Venusian environment tremendously, and without understanding the environment we cannot possibly hope to understand any life that may thrive in it. Even if there is no current nor was there any past life at Venus, it is still critical to understand the extreme greenhouse effect that encompassed Venus. Earth may have a very similar fate in the future.

Furthermore, it is important to understand what the limits for Earth life are in regard to the environmental stressors occurring on Venus. We will gain these by observations from the planned missions and by doing the proposed laboratory experiments. Too much current information about the chemical and physical conditions in the Venusian atmosphere is still based on theoretical speculations and poorly constrained modeling, so the new mission results are very much needed not only to adjust and modify laboratory experiments accordingly, but also obtain a higher confidence in the modeling results.

References: [1] Greaves, J.S. et al. (2020) *Nat. Astron.*, *5*, 655-664. [2] Snellen, I.A.G. et al. (2021) *Astron. Astrophys*. *644*, L2 [3] Cockell, C.S. et al. (2021) *Astrobiology*, in press (doi: 10.1089/ast.2020.2280). [4] Schulze-Makuch, D. et al. (2004) *Astrobiology*, *4*, 11-18. [5] Limaye, S.S. (2021) *Astrobiology*, in press (doi: 10.1089/ast.2020.2268). [6] Schulze-Makuch, D. (2021) *Life*, *11*, #255. [7] Schulze-Makuch, D. and Irwin, L.N. (2002) *Astrobiology*, 2, 197-202. [8] Bains, W. et al. (2021) *Astrobiology*, in press (doi: 10.1089/ast.2020.2352). [9] Mogul, R. et al. (2021) *Geophys. Res. Lett.*, 48, e2020GL091327. [10] Bains, W. et al. (2021) *Astrobiology*, in press (doi.org/10.1089/ast.2020.2352) [11] Omran, A. et al. (2021) Astrobiology, in press (doi.org/10.1089/ast.2021.0034) [12] Petrova, E.V. (2018) *Icarus* 306, 163-170. [13] Seager, S. et al. *Astrobiology* 21, in press (doi 10.1089/ast.2020.2244). [14] Rimmer, P.B. et al. (2021) *The Planetary Science Journal* 2, 133.[15] Lincowski, A.P. et al. (2021) *ApJl, 908,* L44. [16] Maus, D. et al. (2020) *Sci. Rep, 10,* 1-7. [17] Schulze-Makuch, D. et al. (2011) *Astrobiology* 11, 241-258. [18] Meckenstock, R.U. et al. (2014) *Science* 345, 673-676. [19] De Vera, J.-P. (2014) *Planet. Space Sci.* 98, 182-190. [20] Schulze-Makuch, D. et al. (2005) *J. Geophys. Res.* 110, E12S23. [21] Heinz, J. et al. (2020) *Life, 10,* #53.