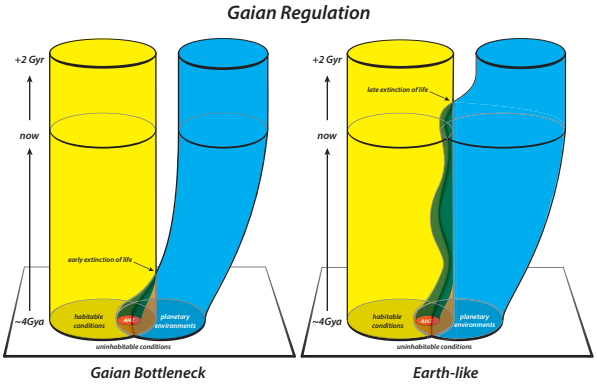
IS HABITABILITY CONSTRAINED BY PHYSICS OR BIOLOGY? THE CASE FOR A GAIAN BOTTLENECK. Charles. H. Lineweaver[1] and Aditya Chopra[1], [1]Planetary Science Institute, Research School of Astronomy and Astrophysics and Research School of Earth Sciences, Australian National University, Australia, charley.lineweaver@anu.edu.au, aditya.chopra@anu.edu.au

The prerequisites and ingredients for life seem to be abundantly available in the universe. However, the universe does not seem to be teeming with life. The most common explanation for this is a low probability for the emergence of life (an emergence bottleneck), notionally due to the intricacies of the molecular recipe. Here we present an alternative explanation: a Gaian bottleneck [1]. If life emerges on a planet, it only rarely evolves quickly enough to regulate temperature through albedo and atmospheric volatiles and maintain habitability. Such a Gaian bottleneck suggests that (i) extinction is the cosmic default for most life that has ever emerged on the surface of wet rocky planets in the universe and (ii) rocky planets need to be inhabited, to remain habitable.

Over the past decade, estimates for the frequency of wet rocky planets in or near the the circumstellar habitable zone (CHZ) have increased. Since, the ingredients of life as we know it (HOCNPS, amino acids, sugars, nucleic acids, HCN and other organics) are based on the most common elements in the universe, we expect them to be present and available on planets throughout the universe [2]. The sources of free energy from geochemical redox potentials or stellar photons should also be ubiquitous. Hence, we suggest that the absence of water and other molecules, the absence of an energy source, or a hypothetically low probability of biogenesis, may not be the dominant limiting factors for long term persistence of life on rocky planets in circumstellar habitable zones.

The habitability of a rocky planet, is strongly influenced by the volatile content of its atmosphere (H_2O CO_2 CH_4) which controls both the albedo and greenhouse warming. Because of the strength, rapidity and universality of abiotic positive feedbacks, the rapid evolution of the atmosphere can lead to both temperatures too hot for life (runaway greenhouse) and loss of water (runaway loss of hydrogen), and can preclude long term planetary habitability. We argue that even if abiogenesis is common on rocky planets, runaway greenhouse effects and volatile loss could be the largest obstacle to life's persistence on initially wet rocky planets throughout the universe.

The emergence of life's abilities to modify its environment and to up- and down-regulate initially abiotic feedback mechanisms (what we call 'Gaian regulation') in the first ~1 billion years to prevent a runaway greenhouse or loss of water could be a significant factor responsible for life's persistence on Earth. We are proposing a sequence of events that can be summarized as: (1) uninhabitably hot, high bombardment rate during planetary accretion (2) cooler, reduced bombardment (3) emergence of life in planetary environments that tend to evolve away from habitability, continuous volatile loss. Then either (4a) the inability of life to control atmospheric volatiles and maintain habitabililty, thus leading to extinction (left panel in figure) or (4b) the rapid evolution of Gaian regulation and the maintenance of habitability (right panel in figure)



The lack of the emergence of such Gaian regulation (a Gaian bottleneck), and the resultant extinction, may be the most common fate of planetary life. The persistence of life on Earth would then be an exception, rather than the rule. And the emergence of life could be much more common than its long term persistence.

The width of the CHZ is usually considered to be a function of physics and chemistry [3]. If Gaian regulation plays the dominant role in surface temperature regulation by biogeochemical cycles or by maintaining liquid water at the surface [4] then the width of the CHZ or even its exsistance would depend more on biology than physics and chemistry. Liquid water on the surface of a planet (particularly old planets) would then not just be a prerequisite for life, but a plausible biosignature.

References: [1] Chopra, A. & Lineweaver, C.H. (2015, *in prep)*. [2] Lineweaver, C.H. & Chopra, A. (2012) *AREPS, 40,* 597–623. [3] Kopparapu, R.K. et al. (2013) *ApJ*, 765, 131 [4] Harding, S. & Margulis, L. (2010) *Water Gaia,* in Gaia in Turmoil (eds. Crist & Rinker), 41–60.