THE CASE FOR A GAIAN BOTTLENECK: THE BIOLOGY OF HABITABILITY (I.E. THE POTENTIAL NON-DOMINANCE OF ABIOTIC FACTORS IN CREATING CIRCUMSTELLAR HABITABLE ZONES). A. Chopra[1] and C.H. Lineweaver[1,2], [1]Research School of Astronomy and Astrophysics and Research School of Earth Sciences, Australian National University, Canberra, Australia, [2]charley.lineweaver@anu.edu.au

The prerequisites and ingredients for life seem to be abundantly available in the Universe [1]. However, we have yet to find any evidence for extraterrestrial life. A 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. In Chopra and Lineweaver 2016 [2] we present an alternative Gaian bottleneck explanation: If life emerges on a planet, it only rarely evolves quickly enough to regulate greenhouse gases and albedo, thereby maintaining surface temperatures compatible with liquid water and habitability. Such a Gaian bottleneck suggests that (i) extinction is the cosmic default for most life that has ever emerged on the surfaces of wet rocky planets in the Universe and (ii) rocky planets need to be inhabited to remain habitable. In the Gaian bottleneck model, the maintenance of planetary habitability is a property more associated with an unusually rapid evolution of biological regulation of surface volatiles than with the luminosity and distance to the host star.

The habitability of rocky planets is strongly influenced by the volatile content of the atmosphere (H_2O, CO_2, CH_4, H_2) which controls both albedo and greenhouse warming. However, because of the strength, rapidity and universality of abiotic positive feedbacks, the rapid evolution of the atmosphere, probably within the first billion years as happened for Venus and Mars, can lead to both temperatures too hot for life (runaway greenhouse) and loss of water (runaway loss of hydrogen), that can preclude long term planetary habitability.

The most important data needed to constrain, validate or invalidate the Gaian Bottleneck model will probably come from estimates of the strength of the abiotic negative feedback of the carbonate-silicate cycle [3] in the first billion years of Earth's history when the area of continental crust (and therefore the amount of sub-aerial silicate weathering) was probably negligible.

If negative feedback from silicate weathering is to create a stable circumstellar habitable zone during the first billion years, several conditions need to be fulfilled. Sub-aerial or sub-aqueous silicate weathering [4] needs to be strong enough, to make its negative feedback dominate the positive feedbacks from a runaway greenhouse or a runaway ice-albedo glaciation. For this to happen CO_2 should be a dominant greenhouse gas able to resolve the early faint Sun paradox. If another greenhouse gas (e.g. methane [5] or carbonyl sulfide [6]) or another mechanism besides the greenhouse effect [7] can resolve the faint early Sun paradox, the effect of the negative feedback from the carbonate-silicate cycle would be sub-dominant and probably unable to abiotically create a stable circumstellar habitable zone during the first billion years of Earth's history when life emerged.

Biotic regulation could provide the necessary level of negative feedback. However, the emergence of metabolisms and ecosystems that could regulate planetary scale greenhouse gases or albedo may be a rare and quirky result of evolution, and therefore present a Gaian bottleneck to the persistence of life on inherently unstable planets.

References: [1] Lineweaver, C.H. and Chopra, A. (2012) *Ann. Rev. Earth Planet. Sci*. 40:597-623 [2] Chopra, A. and Lineweaver, C.H. (2016) *Astrobiology*, 16, 1, 7-22 [3] Walker, J.C.G., Hays, P.B. and Kasting, J.F. (1981) *JGR*, 86, C10, 9776-978 [4] Coogan, L and Dosso, S.E. (2015) *Earth and Planetary Sci. Letters*, 415, 38-46 [5] Haqq-Misra, J.D., Shawn D. Domagal-Goldman, S.D., Kasting, P.J. and James F. Kasting, J.F. *Astrobiology*. February (2009) 8(6): 1127-1137 [6] Ueno, Y.; Johnson, M. S.; Danielache, S. O.; Eskebjerg, C.; Pandey, A.; Yoshida, N. (2009). *Proceedings of the National Academy of Sciences*. **106** (35): 14784–14789. [7] Rosing, M.T., Bird, D.K., Sleep, N.H., and Bjerrum, C.J. (2010) *Nature* 464:744–747.