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Restarting over: Alternative evolutionary pathways for terrestrial life on oxygen planets

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Oxgen planets: It is by now well established that the extended protostar to main sequence Kelvin-Helmholtz contraction phase of late M dwarfs induces a runaway greenhouse state in habitable zone planets for 0.1-1.0 Ga. Several earth oceans worth of water may be lost due to the photolysis water in the wet stratosphere of the greenhouse atmosphere and the subsequent XUV induced escape of hydrogen to space [1]. Most of the photolytically produced oxygen will however be retained, building up to several hundreds of bars of abiotic oxygen by the end of the initial greenhouse state [2]. The question is then, generically, whether massive primordial oxygen partial pressures would preempt abiogenesis on otherwise habitable planets.

Alkaline hydrothermal vents: Life may have originated on earth in ultramafic hydrothermal vents acting as natural bioreactors [3]. Alkaline hydrothermal systems could have been nearly continuous in distribution in the Hadean, when the absence of oxygen would have allowed them to act as electrochemical flow reactors in which alkaline fluids saturated with hydrogen mixed within a labyrinth of interconnected micropores with relatively acidic ocean waters rich in carbon dioxide [4]. The restricted geometries provided by the thin inorganic walls, possibly containing catalytic Fe(Ni)S, could have allowed for prebiotic reaction cycles and for the subsequent formation of protocells.

Habitable but lifeless oxygen planets: Black smokers and ultramafic hydrothermal vents will form also on planets with a massive oxygen partial pressure. Spatially confined reducing environments are however not enough for life to arise. It is unlikely that the locally produced prebiotic compounds could live long enough on oxygen planets to allow for subsequent concentration processes and that the restricted pores of the vent towers would be rich in catalytic transition metals. Protocells would need to adapt, in addition, during the limited lifetime of their hosting vent (possibly of only a few Ma) to the high toxicity [5] of the oxygen dissolved in the surrounding seawater. The demise of their birthing thermal vent would otherwise spell out their own fate as well.

Reversing the perspective: M dwarfs systems such as the TRAPPIST-1 system [2] are expected to be rich in small planets, with an incidence rate of about 0.2 for habitable zone planets [6]. The milky way may hence harbor around 200*0.75*0.2=30 billion rocky habitable zone oxygen planets, out of which a small but finite fraction will have retained part of their original water reservoir and hence an ocean. A large number of potentially habitable but otherwise sterile exoplanets may hence offer alternative evolutionary pathways for terrestrial life. It has been suggested in this context [7], that ecospheres of prokaryotes and unicellular eukaryotes may be established on exoplanets by laser-propelled miniaturized interstellar probes (the Genesis project).

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