What Synthetic Biology Can Do For Astrobiology. Lynn J. Rothschild. NASA Ames Research Center, Mail Stop 239-20, Moffett Field, CA 94035-1000, USA. lynn.j.rothschild@nasa.gov

Introduction: Astrobiology uses data and approaches from a variety of traditional disciplines such as biology, astronomy and geology to tackle the fundamental questions "Where do we come from?" "Where are we going?" and "Are we alone?" [1] In contrast, the emerging field of synthetic biology is dedicated to the design and construction of artificial biological system "to extend or modify the behavior of organisms and engineer them to perform new tasks" [2]. Suprisingly, synthetic biology could also contribute in fundamental ways to astrobiology.

Where do we come from?: Astrobiology seeks to understand how life has come to be, from the creation of a habitable universe, the formation of biogenic elements and planetary bodies, to the origin and evolution of life itself. There is a flurry of activity in the synthetic biology community attempting to create life [3] and its components, including artificial organelles [4-6]. Of course successful production of a living organisms or even its components does not mean that life on Earth arose that way, but it may suggest alternate pathways that occurred on earth or elsewhere. It may also provide a living analog for what did happen on Earth.

Where are we going?: The future tends to be virtually ignored by the astrobiology community, but it is arguably the one question that is most imperative as it has significant impacts from the moral to the financial, the social to the question of the existence of life on earth itself. The future will involve an increasing presence of terrestrial life elsewhere. Synthetic biology is likely to play a vital role in this future. It can be used to expand the capacity of terrestrial life to inhabit extraterrestrial conditions. And, as the Earth itself changes beyond the extremophiles that evolution has produced, synthetic life will be able to leapfrog evolution when the latter moves too slowly to keep up with a changing environment.

Are we alone?: The search for life elsewhere relies on using life on Earth to define a minimum envelope for life [7]. But studying the limits of extremophiles under different environmental conditions we can be assured that there is nothing about these condition *per se* that precludes life.

An interesting feature of life on Earth is that it forms a patchy distribution. There is not an infinite continuum of either species or gene sequences, but rather localized peaks in adaptive space (Fig. 1). So too all potential niche space for life may be occupied. Is it because of technical difficulty, for example, that particular sequence never evolved or that particular niche simply does not exist on earth? Synthetic biology is uniquely poised to answer these questions. For example, on the gene level all potential combinations in sequence space may be created and tested for activity. [e.g., 8] Thus, evolutionary biology will better understand the reasons for the distribution of life on Earth. In the process, our starting hypothesis for the envelope for life may be expanded.

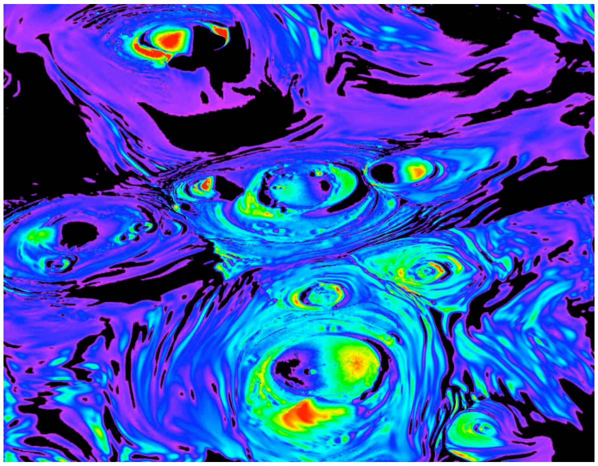

Fig. 1. The patchy nature of adaptive space. Neither organisms nor genes form a complete continuum. Here this is represented by the red peaks (actual species or genes) down to maladapted or possibly lethal black pools. When a species travels from one adaptive peak to another the peak shifts in niche space. But why are there empty spaces? Is it because of evolution has not occupied these due to chance or because organisms in these spaces are unfit to survive? Similarly, this diagram can be interpreted to represent niche space. Are there unoccupied niches because the niches do not exist on Earth, the vagaries of evolution or because they preclude life for physical and chemical reasons, such as extreme heat?

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