

Many of the features that are thought of as biosignatures – including the mediation of chemical and physical processes with speed, specificity, and selectivity – result directly or indirectly from life’s unique capability to mediate and direct energy flux. As such, it is important to consider the impact that differences in energy flux may have on the quantity and quality of evidence for life.

Earth differs from every other body in our solar system in the magnitude of biologically-usable energy flux into a liquid water environment. On a global basis, the capture of light energy into photosynthesis and the flux of chemical energy represented in the products of that photosynthesis (organic material + O₂) are about six and four orders of magnitude larger, respectively, than the flux of energy represented in geochemical sources. Our conception of what an inhabited world “looks like” and our intuition about how to search for life are based in this high-energy context.

Energy fluxes on worlds beyond Earth may be better approximated by the million-fold smaller flux provided to Earth’s biosphere by geochemical sources. As a result, the nature, abundance, and quality of evidence for life that could be expected on an inhabited extraterrestrial world within our solar system may differ profoundly from that found on Earth. Understanding this potential difference in quantitative terms provides important context for the formulation of life detection strategies.

The influence of energy flux on biosignatures can be evaluated through reference to the two basic purposes into which life partitions energy flux:

(1) Life expends energy to sustain existing biomass in a metabolic steady state (metabolically functional but non-growing). The formal representation of this relationship in the traditional microbiology literature equates biomass directly with energy flux. The direct implication is that worlds having lower energy flux will have correspondingly lower potential to support biomass. Life detection strategies that directly target extant organisms should therefore be prepared to encounter average biomass densities that may be many orders of magnitude smaller than those found in most of Earth’s surface environments

(2) Life expends energy to synthesize new biomass. An end-member case in which new biomass is created at the energy-limited rate and the corresponding cells

are immediately destroyed (so that the energy partitioned to cell maintenance is minimized) establishes an upper bound on the rate at which biological material can enter a bulk global pool. For a specified bulk concentration $[i]$ of any particular biological compound, i , or for biologically produced matter overall, this synthesis rate, R_i , defines a characteristic time scale $\tau_i = [i]/R_i$. τ_i can be thought of as (a) the minimum time required for biosynthesis to yield a specific bulk concentration (e.g., a detection threshold) of i , and (b) the average residence time of i within a bulk pool when $[i]$ is held in steady state through a balance between biosynthesis and attrition by physical, chemical, or biological consumption. τ_i becomes an important quantity in considering the potential utility of enantiomeric excess (as a product of homochiral biosynthesis) as a biosignature. Spontaneous racemization of amino acids acts to “erase” the signature of homochiral synthesis over time scales that may range from hundreds to hundreds of thousands of years, depending on temperature. For environments in which low energy flux translates to low rates of biosynthesis, including the synthesis of homochiral amino acids, amino acid residence times in pools having detectable concentrations may compare to or significantly exceed the time scale for racemization. This and similar consequences of long residence times should be considered in the formulation of life detection strategies based on detection of biologically-produced species.

Fluxes of biologically-useful energy on potentially habitable worlds within our solar system are, at present, not well constrained. Improving such constraint has the potential to inform priorities in the formulation and targeting of search-for-life strategies, based on the implications of energy flux for the abundance and quality of biosignatures overall, and in specific categories.