THE LADDER OF LIFE DETECTION

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Life detection involves:
1- **Searching for biosignatures** (features that are evidence of ongoing or past biological processes)
2- **Establishing context** (properties and processes inherent to the sample's current and past conditions, e.g. environments).

The Ladder aims to **stimulate** discussions that work to:
- **identify** potential biosignatures
- rigorously **evaluate** their credibility and detectability

to inform the development of **missions** seeking to find life in habitable environments found on **Mars**, **ocean worlds**, and **exoplanets**.

Any suggestions to improve this tool?
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	Quantifiable	Contamination-free	Repeatable	Detectable	Survivable	Reliable	Compatible	Last-resort [4]
Why?	***Avoid false negatives***	***Avoid false positives***	***Avoid fluke***	***Avoid false negatives***	***Avoid false negatives***	***Avoid false positives***	***Consistent with what we know of life [2]***	***Precludes abiotic origin***
Test	*Positive controls*	*Neg. controls* *Blanks*	*≥ N per sample*	*Positive controls*	$\tau_{residence} > N*\tau_{degradation}$	*Measure [bio]≠[abio]*	*Decision rules*	*Decision rules*
	Signal for feature of life selectively quantified above instrumental limit of quantitation, within response time and dynamic range. Encompasses all quantitative measures of instrumental performance [1].	Signal for feature of life not selectively detected in abiotic samples Distinguish indigenous signals from contamination signals arising from: •Hardware •Other samples (cross-contamination)	N=3 typical burden of proof in microbiology and chemistry, for as many samples as needed to capture the heterogeneity of the setting	Physical, chemical, or geological conditions in the sample's current environment do not preclude the measurement, e.g.: • Rxn of organics with oxidant upon heating • Ionization suppression by salts	Physical, chemical, or geological conditions in the suite of environments encountered by the sample between its synthesis and its measurement, e.g.: • Photo-/radiolysis • Racemization, have not destroyed feature	Distinguishable from abiotic backgrounds from any of the environments encountered by the sample between its synthesis and its measurement [bio] / ([bio]+[abio]) > instrument precision	The feature must not be excessively different from what is known of life on Earth (specificity vs. genericity). Limits can be pushed within bounds [3]. e.g.: • Organic molecules • Temperature not too high.	The (set of) measurement(s) precludes an abiotic origin with sufficiently little ambiguity. This criterion has been informally adopted by the astrobiology community as a standard.

References: [1] Armbruster & Pry (2008) *Clin Biochem Rev* 29:S49. [2] NRC (2007) *The Limits of Organic Life in Planetary Systems*. [3] Wolfe-Simon et al. (2010) *Science* 332:1163. [4] Sagan et al. (1993) *Nature* 365:715.

	RUNG Roughly, subjectively ordered by: 1. decreasing strength of evidence for life 2. increasing ease of measurement	FEATURE Listed in no specific order within a given rung Features in green evidence extant life	MEASUREMENT TARGET		LIKELIHOOD …that the feature would be a biosignature, given the criteria to the right	INSTRUMENTAL CRITERIA Quantifiable Detectability	 Contamination-free Likelihood of false positive	 Repeatable	CONTEXTUAL CRITERIA Detectable Detectability	 Survivable Likelihood of false negative	 Reliable Ambiguity of feature	 Compatible Specificity to Earth life	 Last-resort Ambiguity of interpretation
LIFE	**Darwinian evolution**	Changes in inheritable traits in response to selective pressures	Not possible under mission constraints	• In situ • Sample return	No	-	-		-	N/A (extant)	-	-	-
	Growth & Reproduction	Concurrent life stages or identifiable reproductive form, motility	Cell(-like?) structures in multiple stages	• In situ • Sample return	Low	Hard	Low		Med (don't identify stages, timing off, sample size low)	High?	Ambiguous. What is a cell? What morphological differences exist?	Earth	Med / High
	Metabolism	Major element or isotope fractionations indicative of metabolism	Deviation from abiotic fractionation controlled by thermodynamic equilibrium and/or kinetics	• Remote sensing • In situ • Sample return	Low / Med	Easy	High		Medium	High	Hinges on understanding of context	Earth?	Low
		Response to substrate addition	Waste output (compound, heat)	• In situ • Sample return	Low / Med	Easy	Low		High	N/A (extant)	Hinges on understanding of context	Earth	Medium
		Co-located reductant and oxidant	Deviation from abiotic distribution controlled by thermodynamic equilibrium and/or kinetics	• Remote sensing • In situ • Sample return	Med / High	Med (linked to specificity of instrument)	Low / Med	Number of replicates depends on: • Characteristics of the instrument, • Heterogeneity of the sample, • Likelihood of systematic errors, • Required values of the relevant statistical parameters, • Value and cost of information.	Med / High	High	Mixed reactions, large inventory of chemistries	Generic	Low / Med
	Molecules & Structures Conferring Function	Polymers that support information storage and transfer for terran life (DNA, RNA)	Abundance	• In situ • Sample return	Low	Hard (instrument specificity must be high); RNA hard to measure on Earth	DNA: high; RNA: low (reactive)		Low (technology limited, only terran); RNA highly reactive	Low (hydrolysis in water)	Reliable	Earth	Negligible
		Structural preferences in organic molecules (non-random and enhancing function)	Polymer with repeating charge	• In situ • Sample return	Low / Med	Need a lot of material and overprinting must be discernable	Low		Med / High	Low (hydrolysis in water, diagenesis)	How much preference needed to detect?	Generic	Low
			Enantiomeric excess > 20% in multiple amino acid types	• In situ • Sample return	High	How much excess necessary?	Low		Low	Medium	Mixed sample both processes present	Generic	Low
		Pigments as evidence of non-random chemistries (e.g. specific pathways)	Spectral feature and/ or color, otherwise see "structural preferences"	• Remote sensing • In situ • Sample return	Low / Med	Easy (fluorescence)	Low		Low (limitation of what we are looking for)	Low (diagenesis)	How to define pigment as we don't know it?	Earth (can one abstract?)	Very low
SUSPICIOUS BIOMATERIALS	**Potential biomolecule components**	Organics not found abiotically (e.g. hopanes, ATP, histidine)	Presence	• In situ • Sample return	Medium	Easy if enough material	Low		High	High	Low	Earth?	High
		Complex organics (e.g. nucleic acid oligomers, peptides, PAH)	Presence	• In situ • Sample return	High	Easy if enough material	Low		High	Medium	Abiotic production known	Generic	Med / High
		Monomeric units of biopolymers (nucleobases, amino acids, lipids for compartmentalization)	Presence	• In situ • Sample return	Med / High	Limit of detection, need a lot of material	High		High	Med (diagenesis)	Abiotic pathways known	Generic	Medium
	Potential metabolic byproducts	Distribution of metals e.g. V in oil or Fe, Ni, Mo/W, Co, S, Se, P	Presence	• In situ • Sample return	Medium	Easy except background issue	Low		High	High	Background known	Generic	Medium
		Patterns of complexity (organics)	Deviation from equilibrium (P(Poisson distribution of pathway complexity) < 0.01?) or abiotic kinetic distribution	• In situ • Sample return	High	Background issue, material limited	Low		High	Medium?	Limited documentation of abiotic vs. biotic differences	Generic	Medium
	Biofabrics	Textures	Biologically mediated morphologies, preferably with co-located composition	• In situ • Sample return	Medium	Medium	Low		Medium	High?	Highly ambiguous	Earth	High
	Habitability	Liquid water, building blocks, energy source, gradients		Redox, temperature, pH, energy, disequilibria									