AGNOSTIC BIOSIGNATURES

Universal Life Detection Strategies
and applicability to Mars missions

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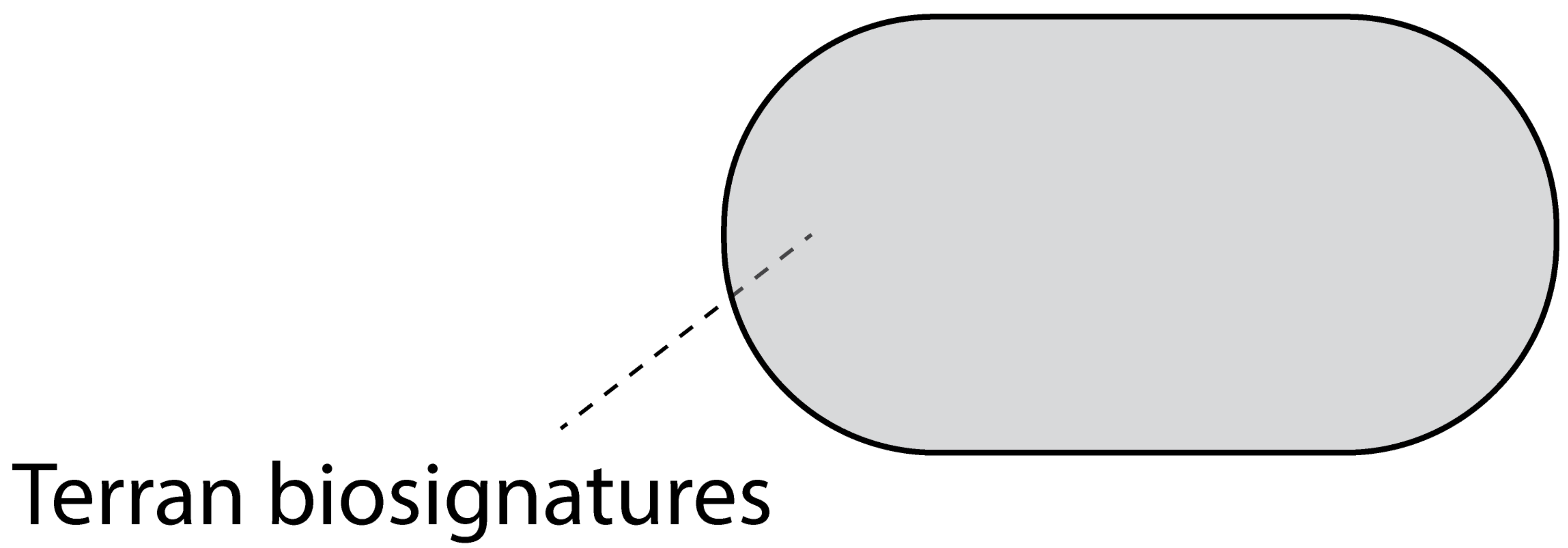
HARVARD UNIVERSITY, UNIVERSITY OF **GLASGOW**, UNIVERSITY OF **TORONTO**

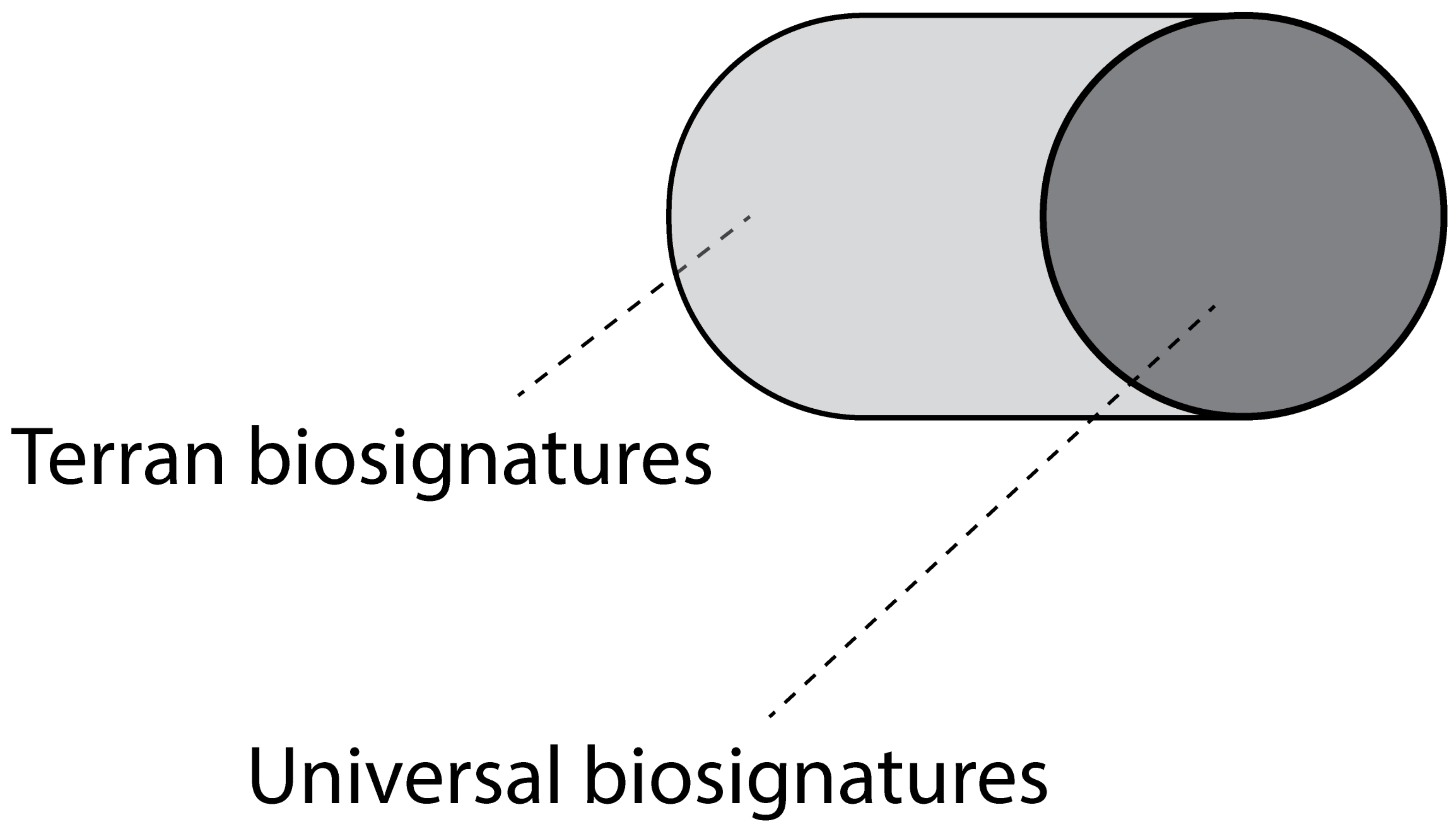
MOTIVATING QUESTIONS

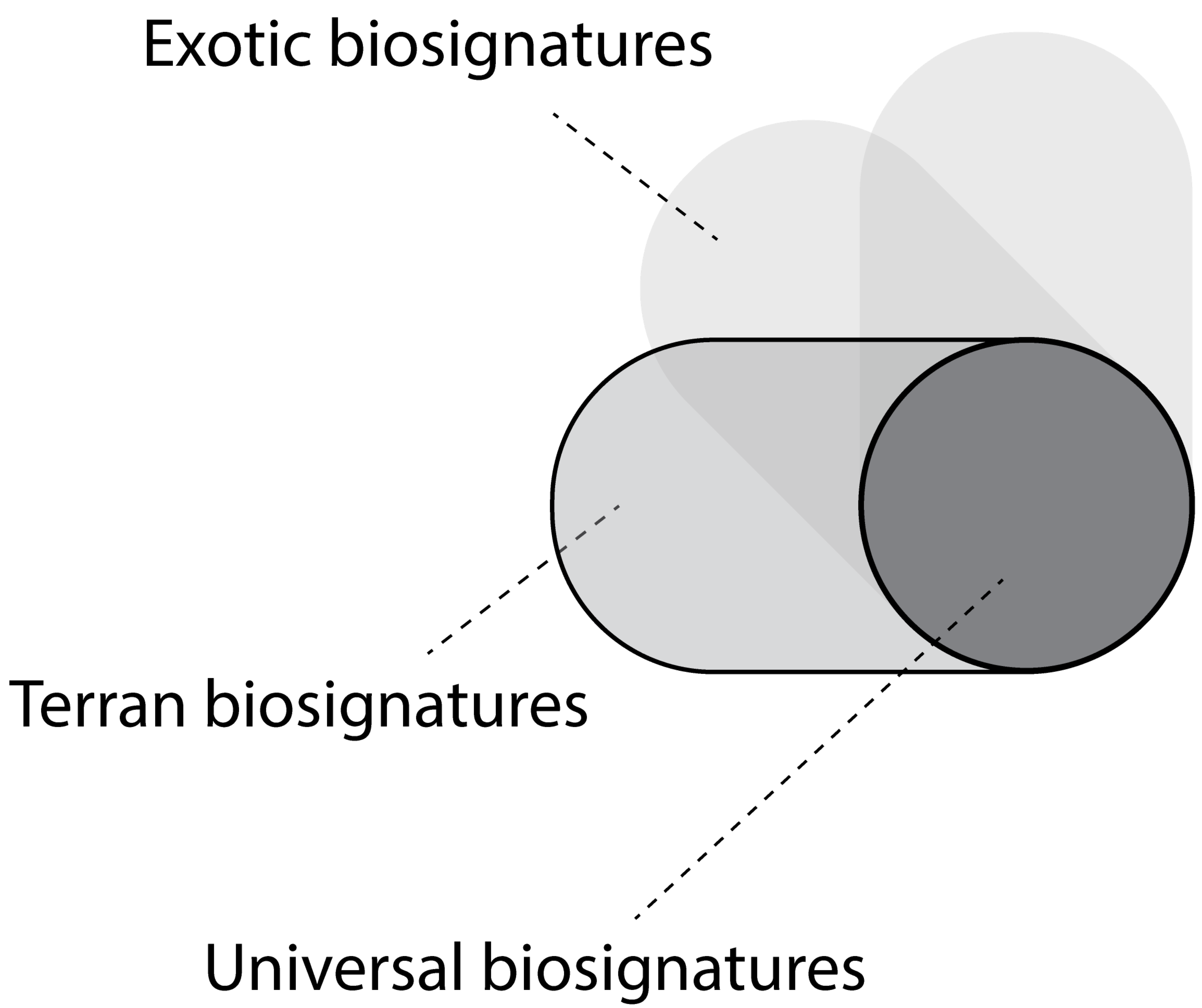
What is the scientific case for searching for extant life?

What are the strategic gaps and the planetary protection concerns of missions searching for extant life?

What **methodologies** and **missions** are currently proposed or are in development for the search for **extant life on Mars**?


Terran biosignatures


Terran biosignatures
Universal biosignatures


Exotic biosignatures
Terran biosignatures
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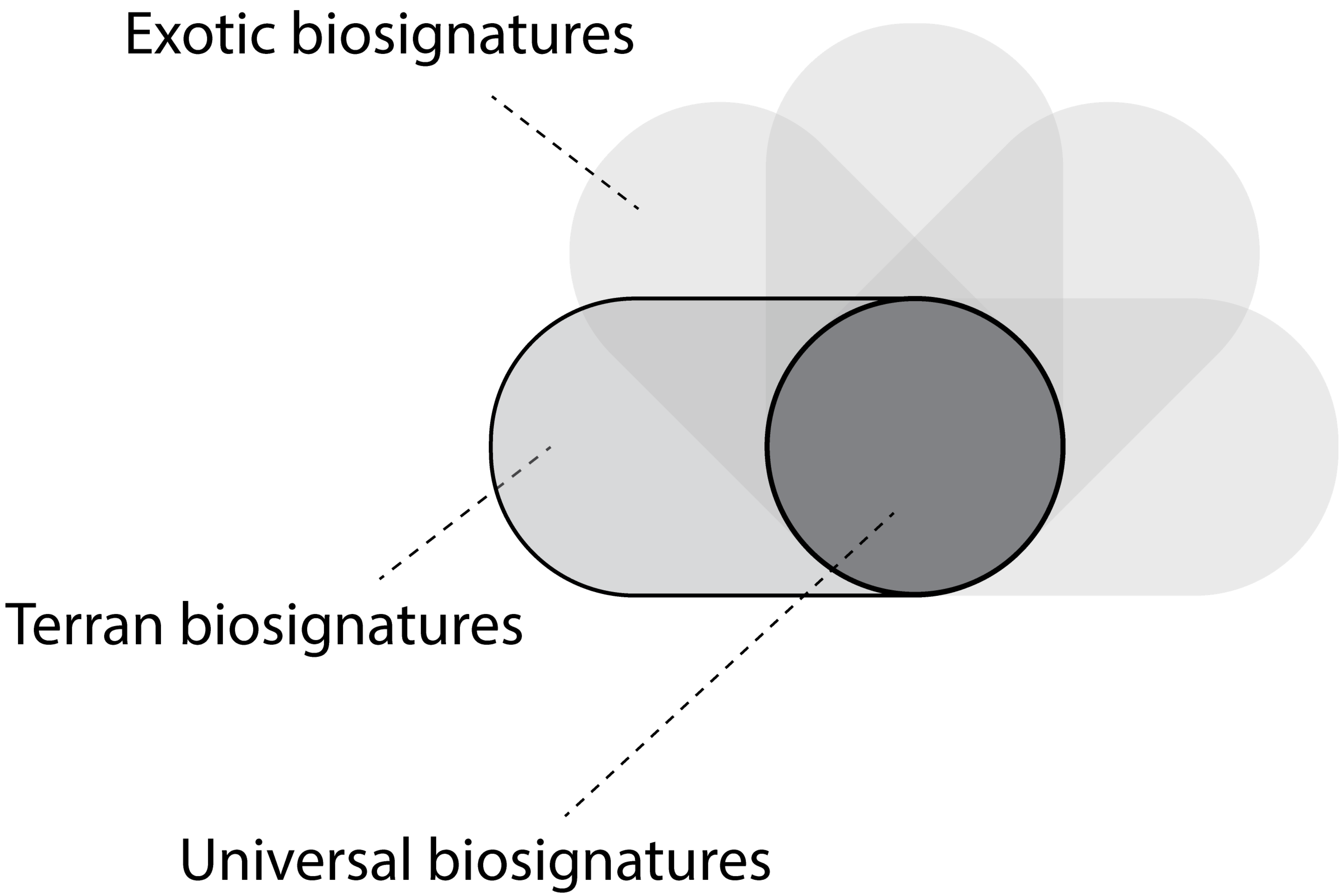
Exotic biosignatures
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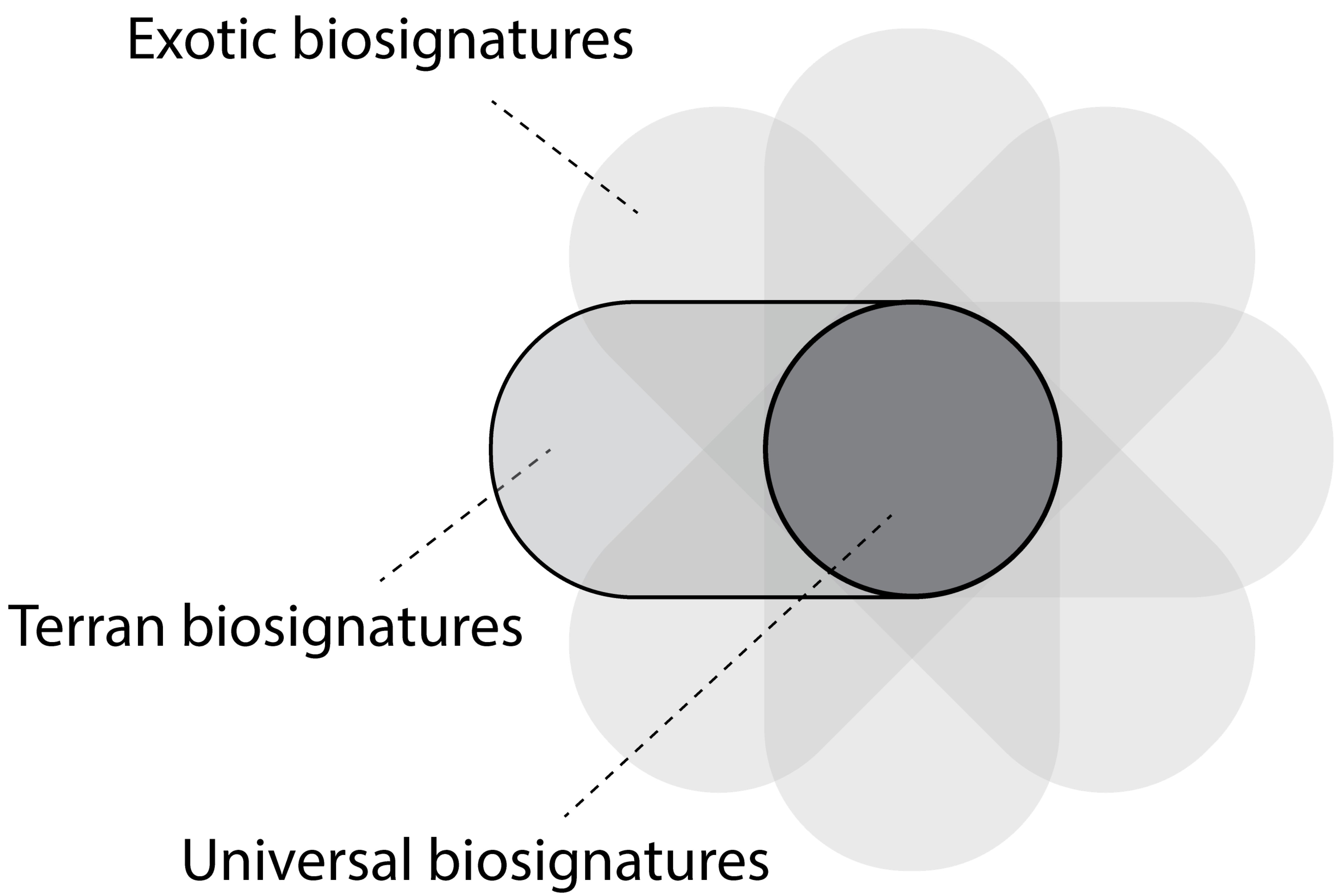
Exotic biosignatures
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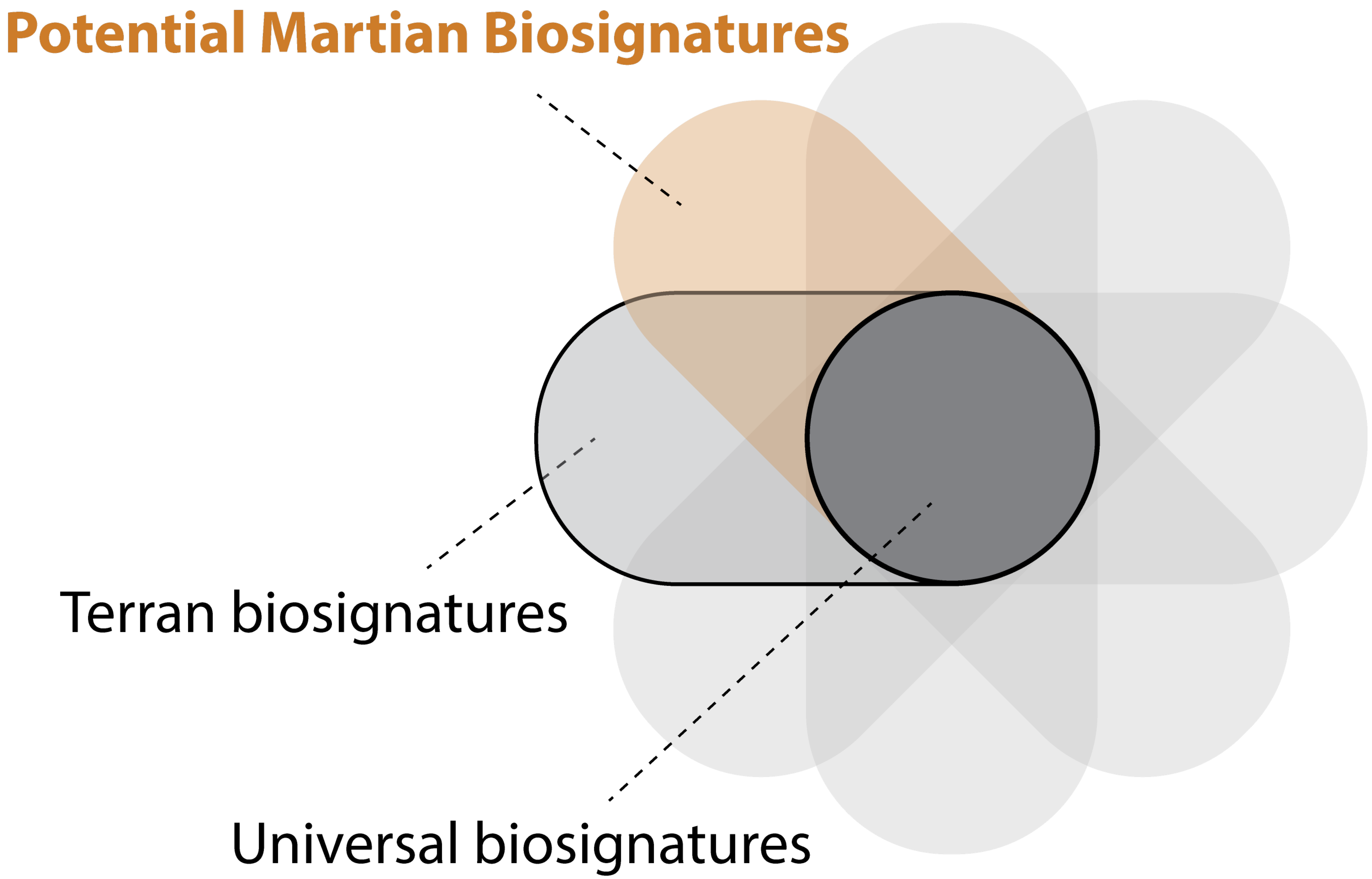
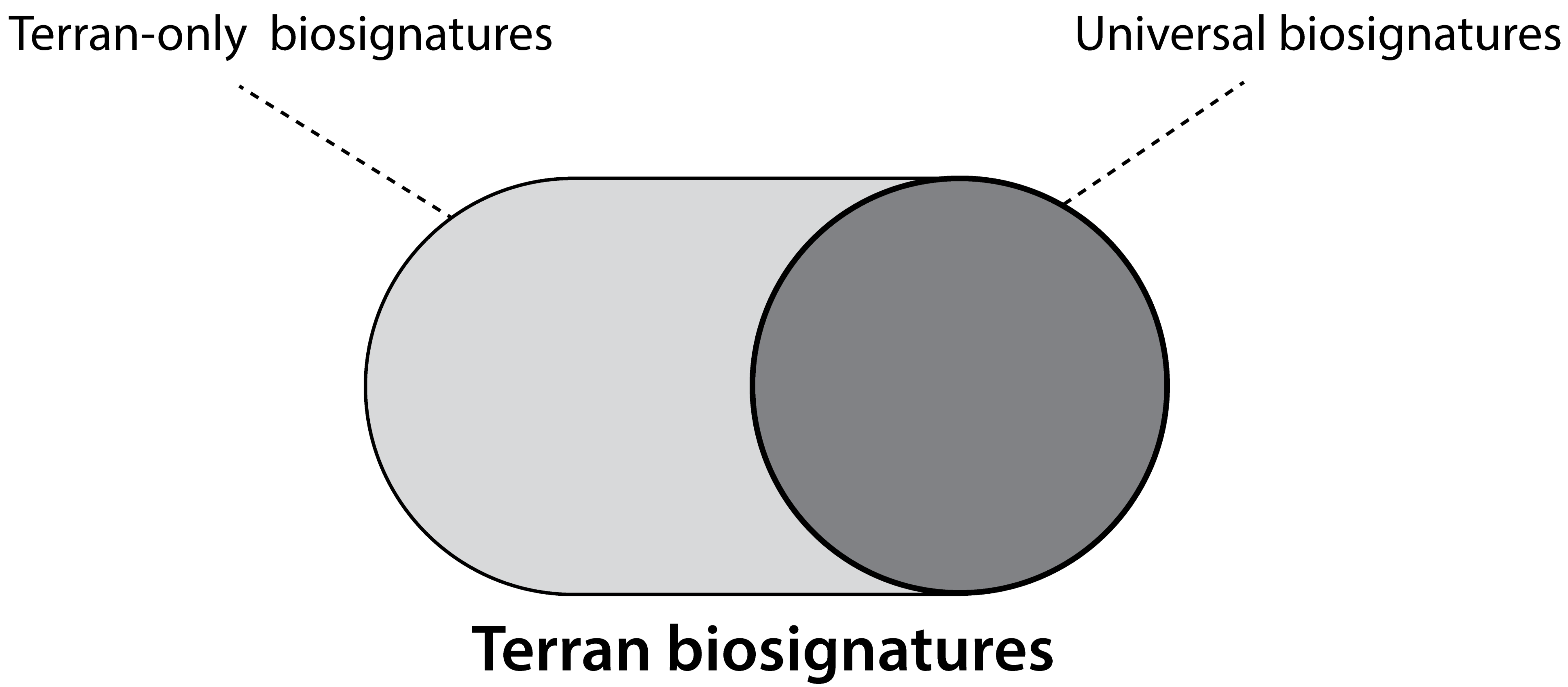
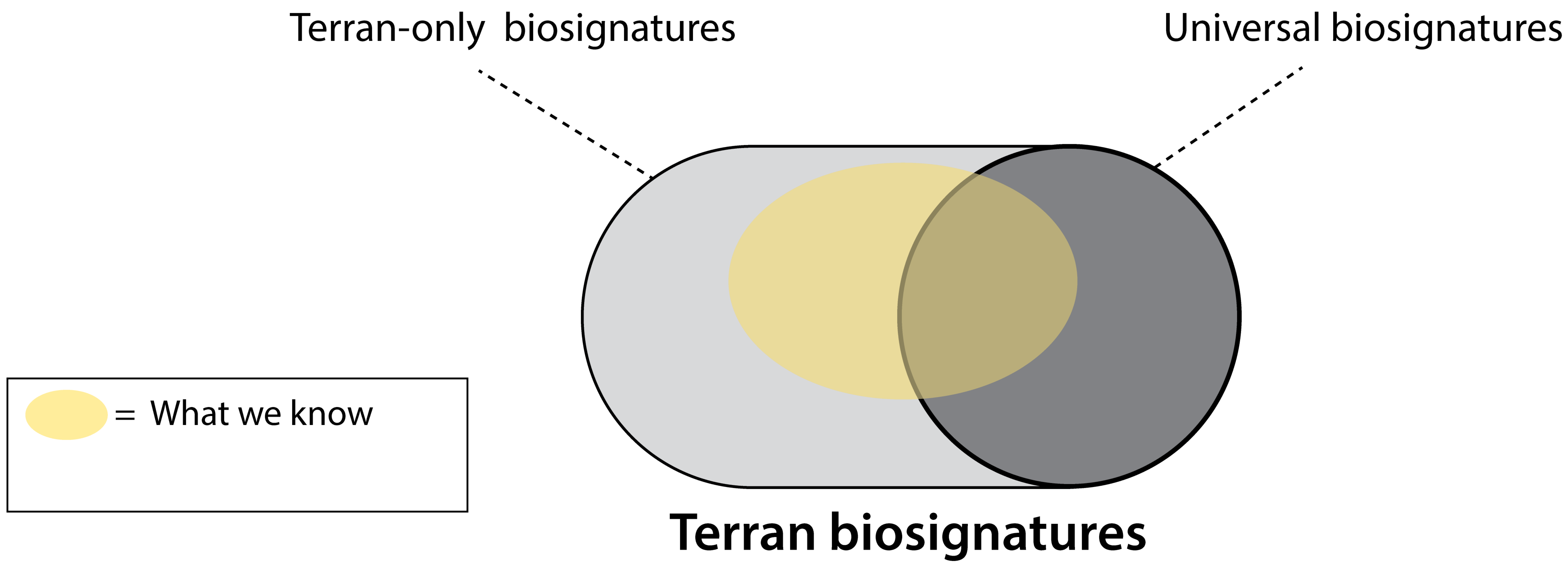
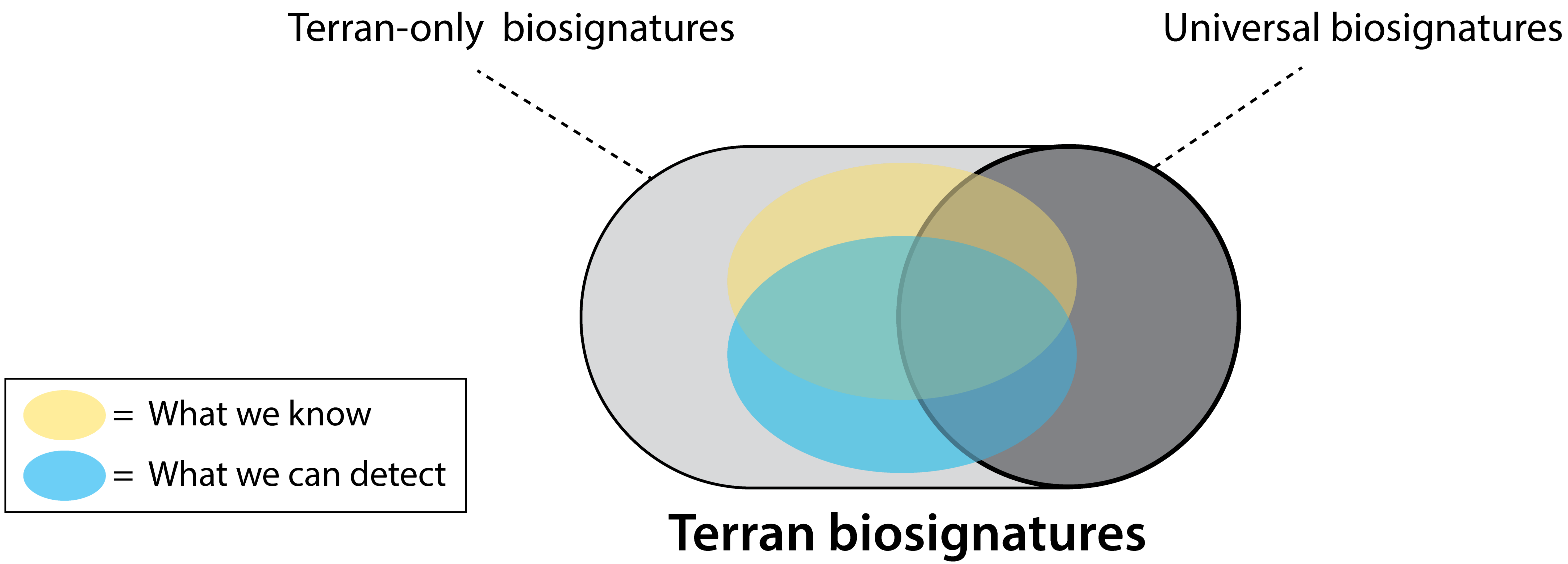
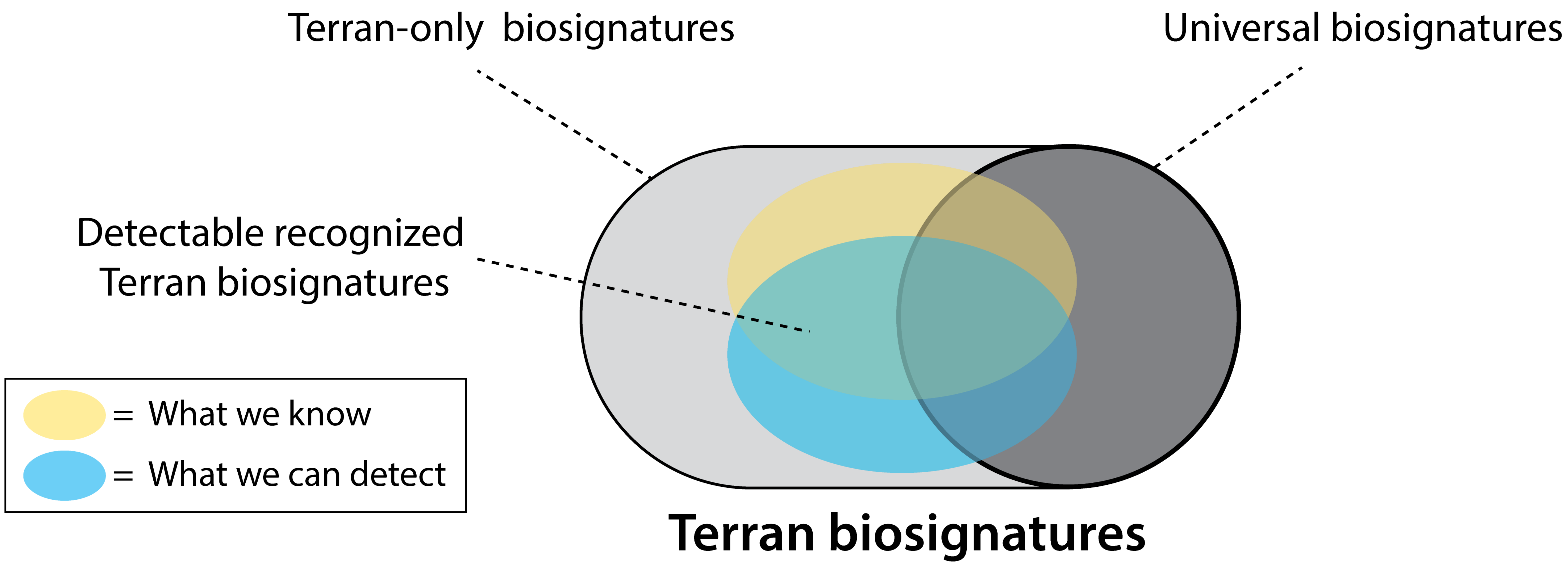

Potential Martian Biosignatures
Terran biosignatures
Universal biosignatures

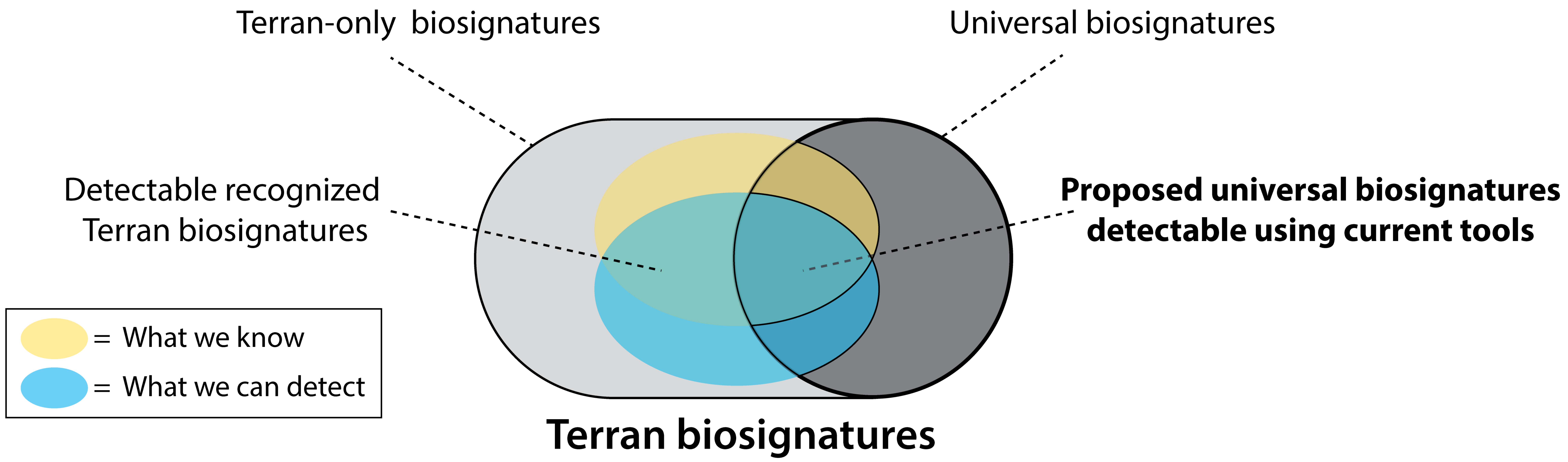
Universal, or "agnostic", **biosignatures are signatures of life** that **do not presuppose** an underlying biochemical system (e.g. Terran biochemistry)


Terran-only biosignatures
Universal biosignatures
Terran biosignatures


Terran-only biosignatures
Universal biosignatures
= What we know
Terran biosignatures


Terran-only biosignatures
Universal biosignatures
= What we know
= What we can detect
Terran biosignatures


Terran-only biosignatures
Universal biosignatures
Detectable recognized
Terran biosignatures
= What we know
= What we can detect
Terran biosignatures


Terran-only biosignatures
Universal biosignatures
Detectable recognized Terran biosignatures
Proposed universal biosignatures detectable using current tools
= What we know
= What we can detect
Terran biosignatures

Steering exploration objectives from looking for specific features of life on Earth to looking for **general features of life** importantly **includes** detecting Terran-like life

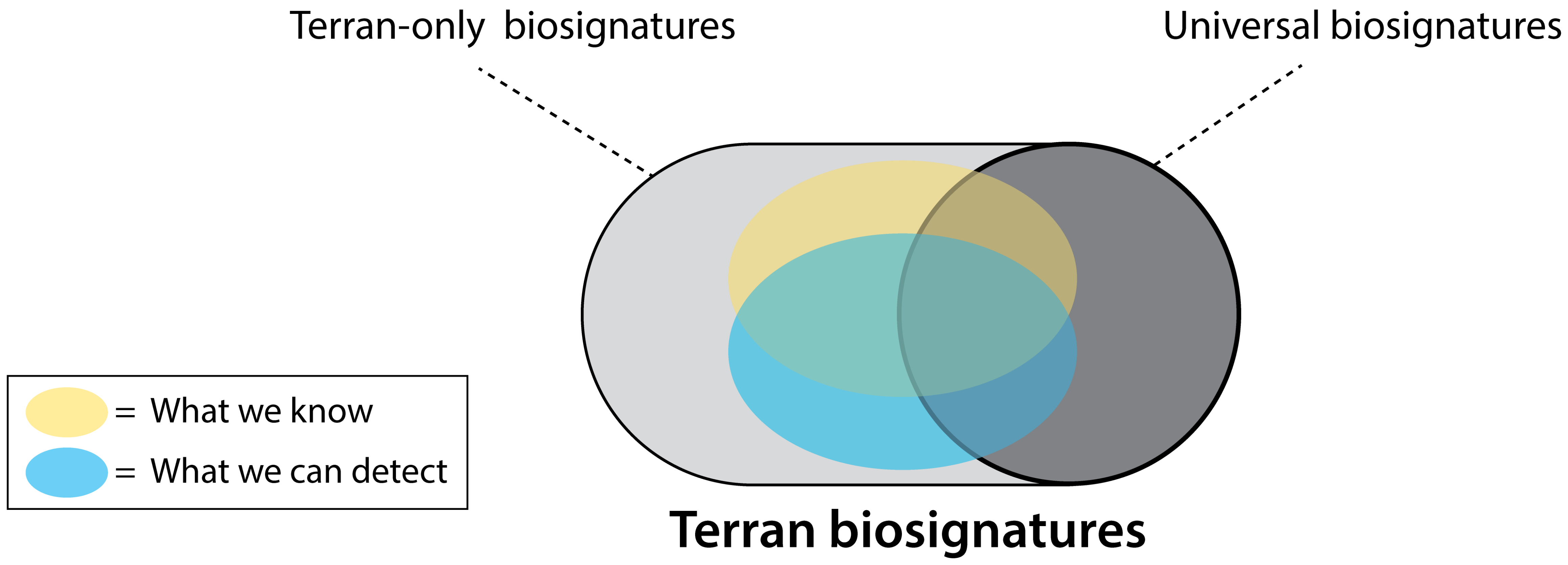
RECOMMENDATIONS

Strong and sustained **support of R&A** to develop **universal theories to recognize signatures of life**

Support of a more **diverse program** of **instrument development** and **maturations**

Implementation of a **wider range of complementary *in situ* science measurements** using **robust statistical methods**

Broadening our knowledge base



Broadening our knowledge base

Top Down Approach

Examine existing data on **key chemical and physical differences** between life and non-life

Collect & curate a comprehensive, standard **reference sample set**

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Collect & curate a comprehensive, standard **reference sample set**

Enhance research on **universal principles of biology**, bio-physical laws, complexity, and OoL

Use **modeling, theoretical, or experimental approaches** to study universal biosignatures

Bottom Up Approach

Broadening our knowledge base

Top Down Approach

Examine existing data on **key chemical and physical differences** between life and non-life

Collect & curate a comprehensive, standard **reference sample set**

Iterate knowledge

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Bottom Up Approach

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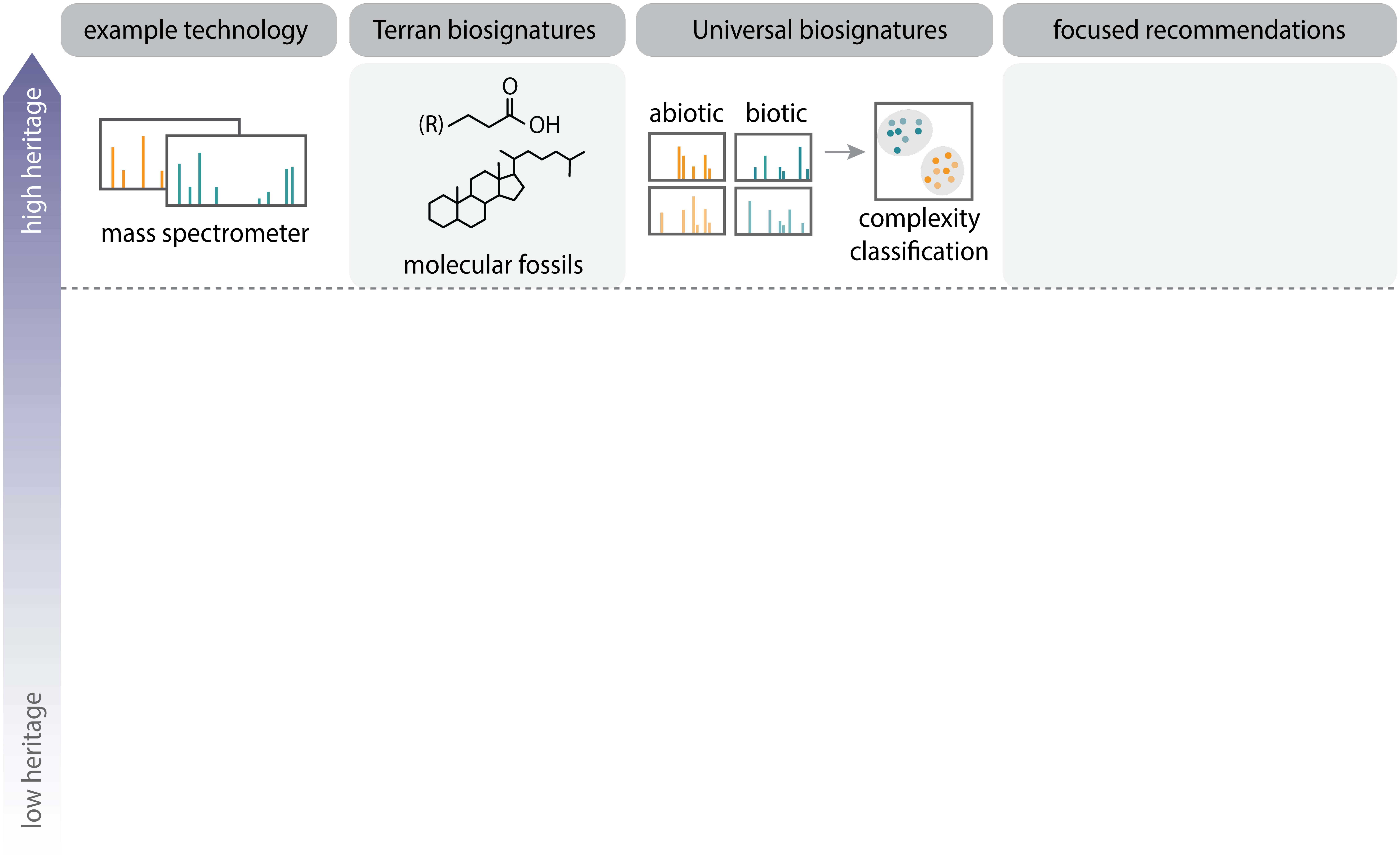
Expanding our detection capabilities

(1) taking advantage of existing **high heritage instrumentation** to perform broader science measurements

(2) supporting technology development that bring **proof-of-concept** studies and instrumentation closer to flight readiness

(3) develop **new flight instruments** to match newly propose universal biosignatures


example technology
Terran biosignatures
Universal biosignatures
focused recommendations
high heritage
low heritage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(R)
O
OH
molecular fossils
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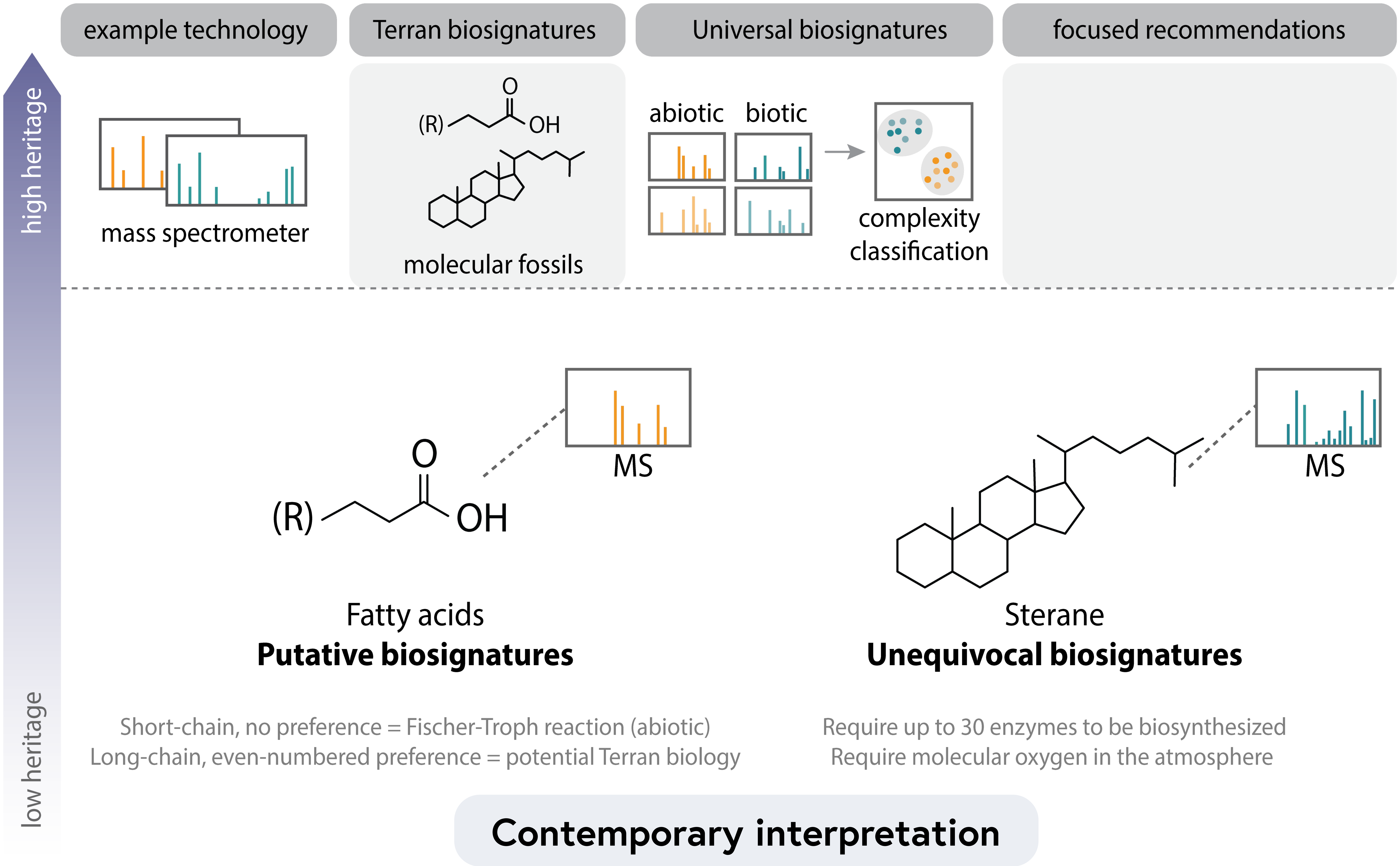
biotic
complexity
classification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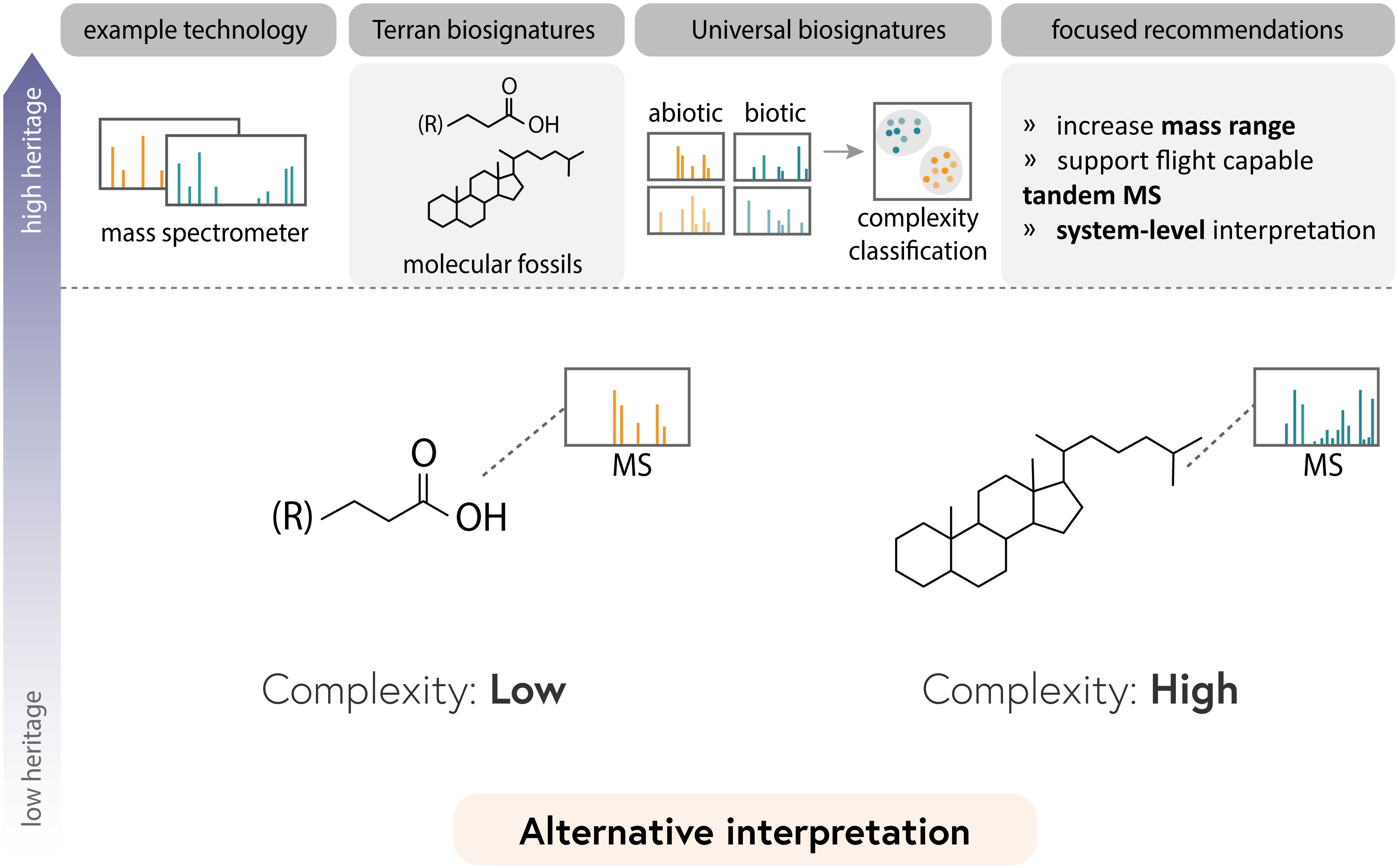
MS
MS
Fatty acids
Putative biosignatures
Sterane
Unequivocal biosignatures
Short-chain, no preference = Fischer-Troph reaction (abiotic)
Long-chain, even-numbered preference = potential Terran biology
Require up to 30 enzymes to be biosynthesized
Require molecular oxygen in the atmosphere
Contemporary interpretation



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mass spectrometer
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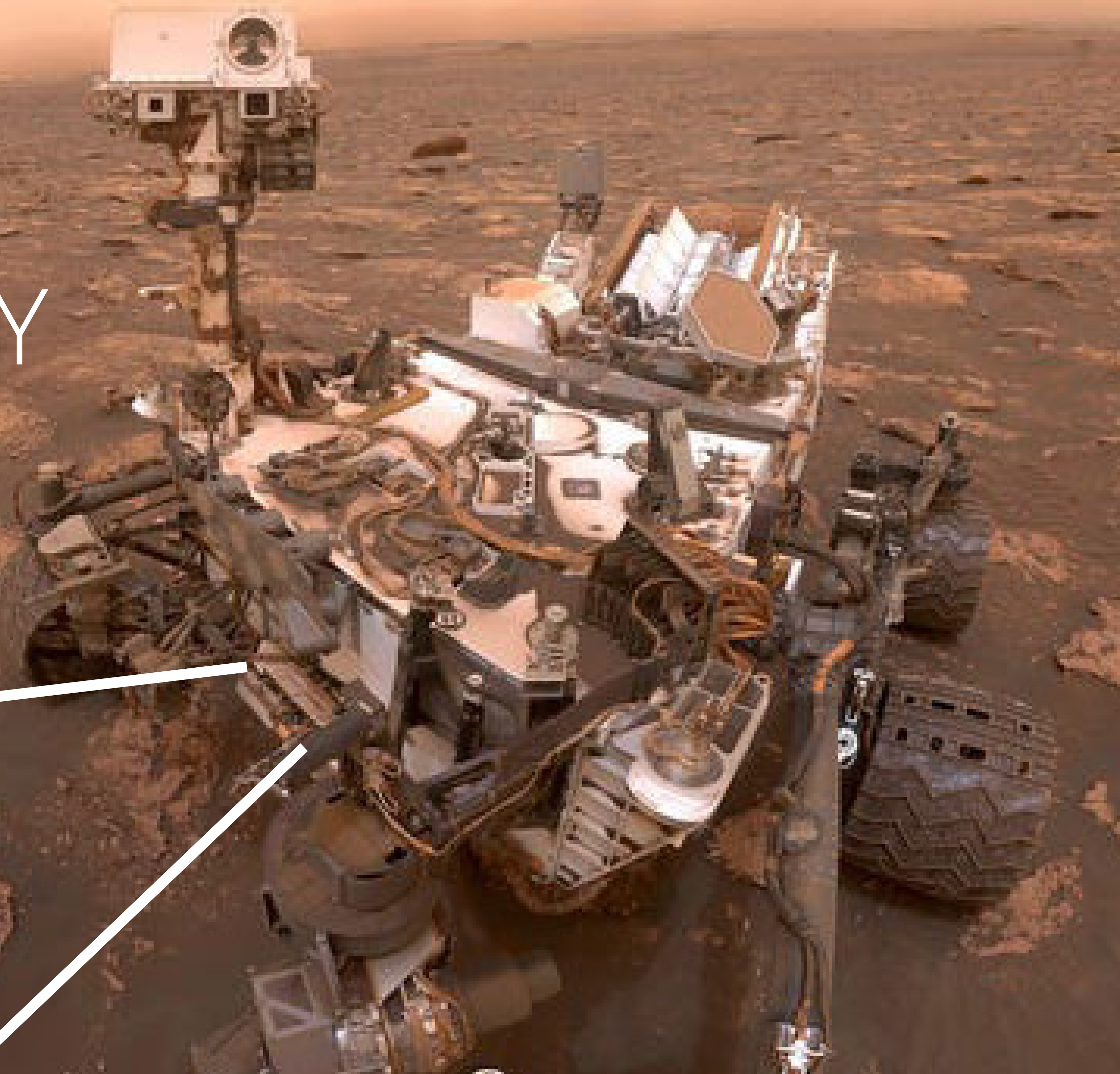
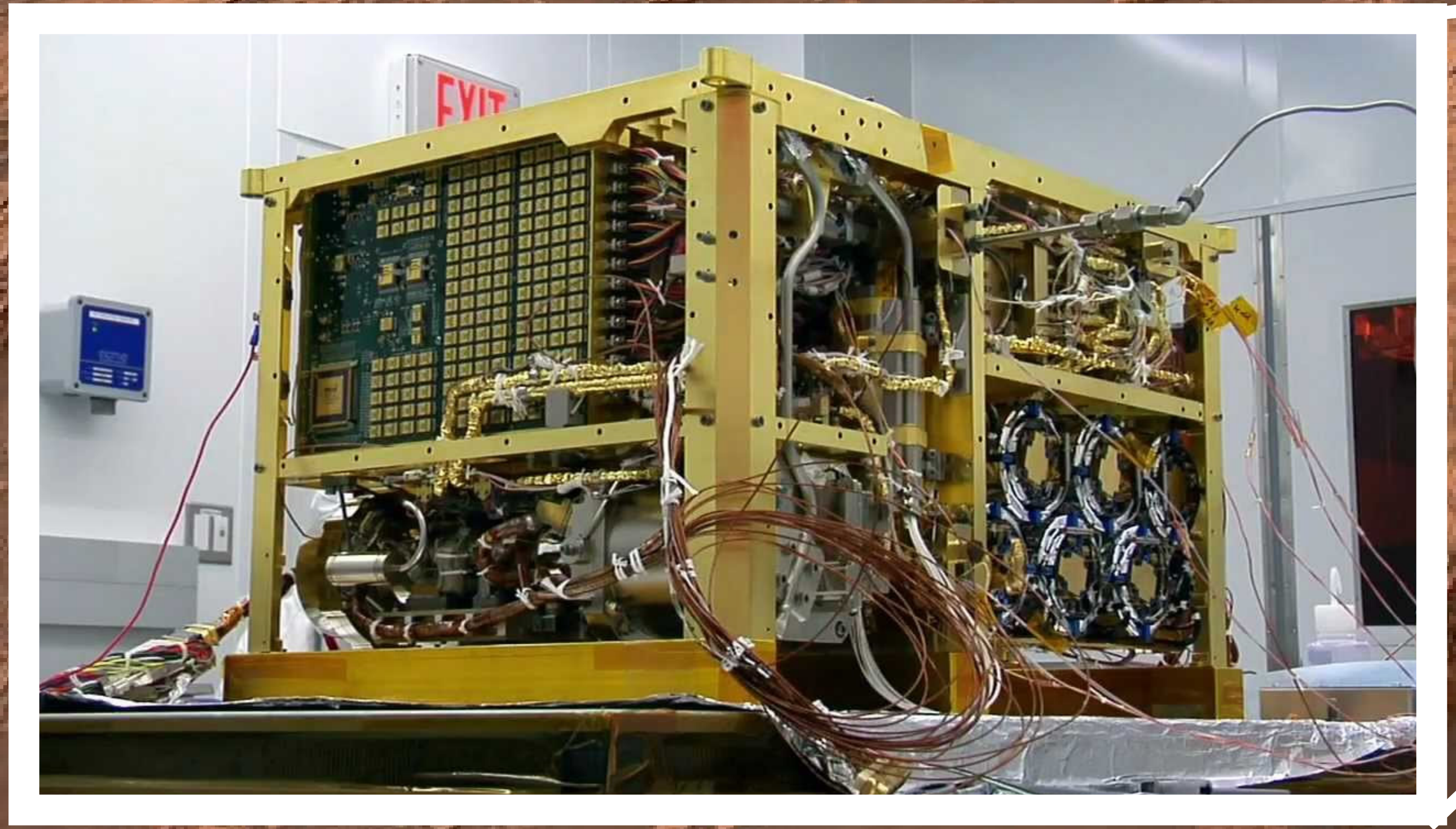
complexity classification
» increase **mass range**
» support flight capable **tandem MS**
» **system-level** interpretation
MS
MS
Complexity: **Low**
Complexity: **High**
Alternative interpretation

CURIOSITY'S
MARS SCIENCE LABORATORY





SAMPLE ANALYSIS AT MARS
(SAM)

MEASUREMENT CAPABILITIES:

- » **Pyrolysis**
- » **GC-MS**
- » **Chemical derivatization**
- » Mass range of **2-535 Da** to identify **complex molecules**


ROSALIND FRANKLIN
EXOMARS 2022
MARS ORGANIC
MOLECULAR ANALYZER
(MOMA)
The **Dragonfly Mass Spectrometer (DraMS)** aboard the Dragonfly Mission will also utilize similar techniques to explore the complexity of Titan's chemistry.
MEASUREMENT CAPABILITIES:
» **GC-MS** with **derivatization**
» **laser desorption** mass spectrometry
» Mass range of **50-1000 Da** with **tandem mass spectrometry** to explore **chemical complexity**

Life detection instrumentation faces an uphill battle on the road to **flight readiness**

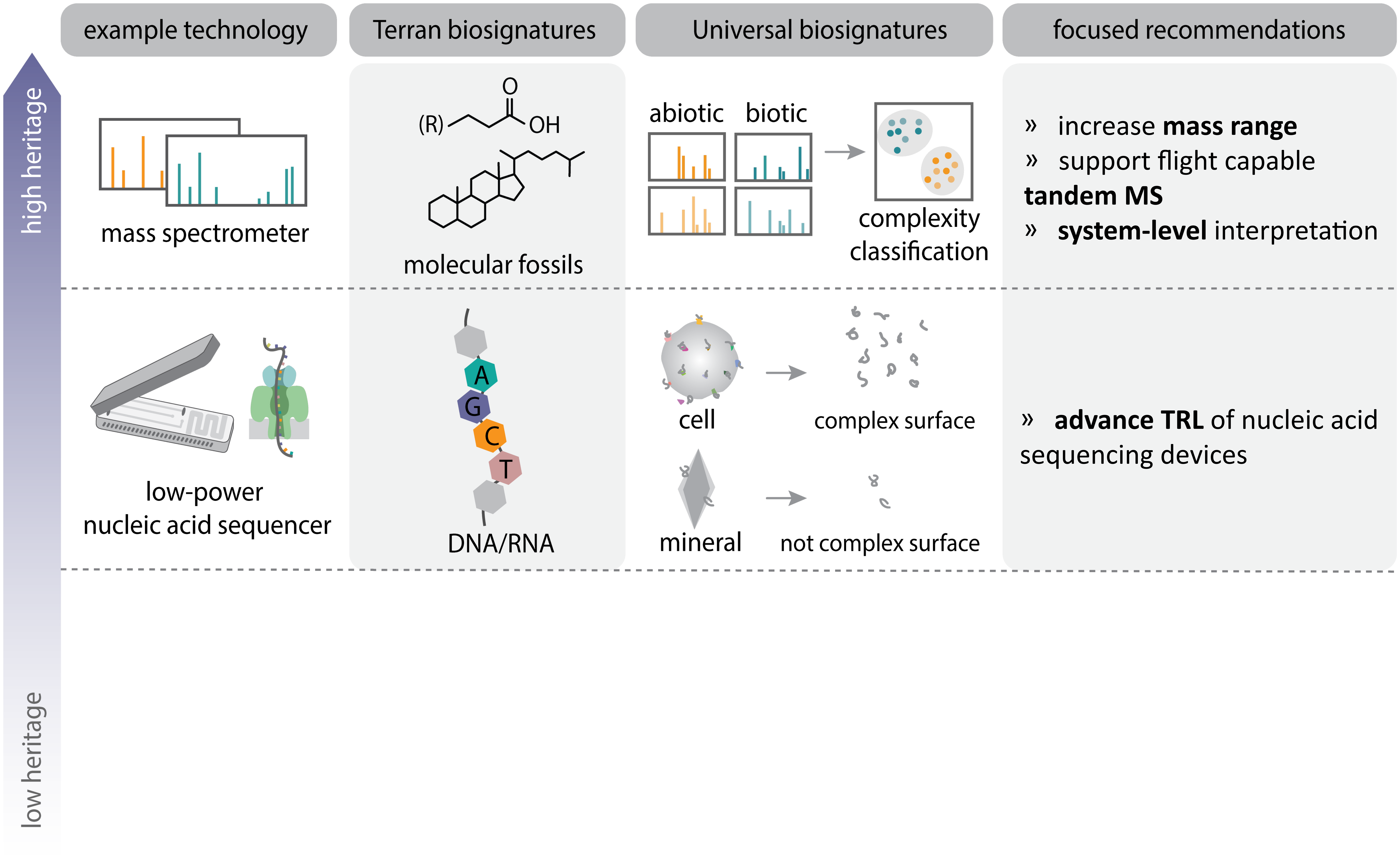
See NASEM Decadal Survey White Paper by the ***Network for Life Detection (NfoLD)***
Schmidt et al. 2020

Expanding our detection capabilities

(1) taking advantage of existing **high heritage instrumentation** to perform broader science measurements

(2) supporting technology development that bring **proof-of-concept** studies and instrumentation closer to flight readiness

(3) develop **new flight instruments** to match newly propose universal biosignatures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» **system-level** interpretation
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» **advance TRL** of nucleic acid sequencing devices

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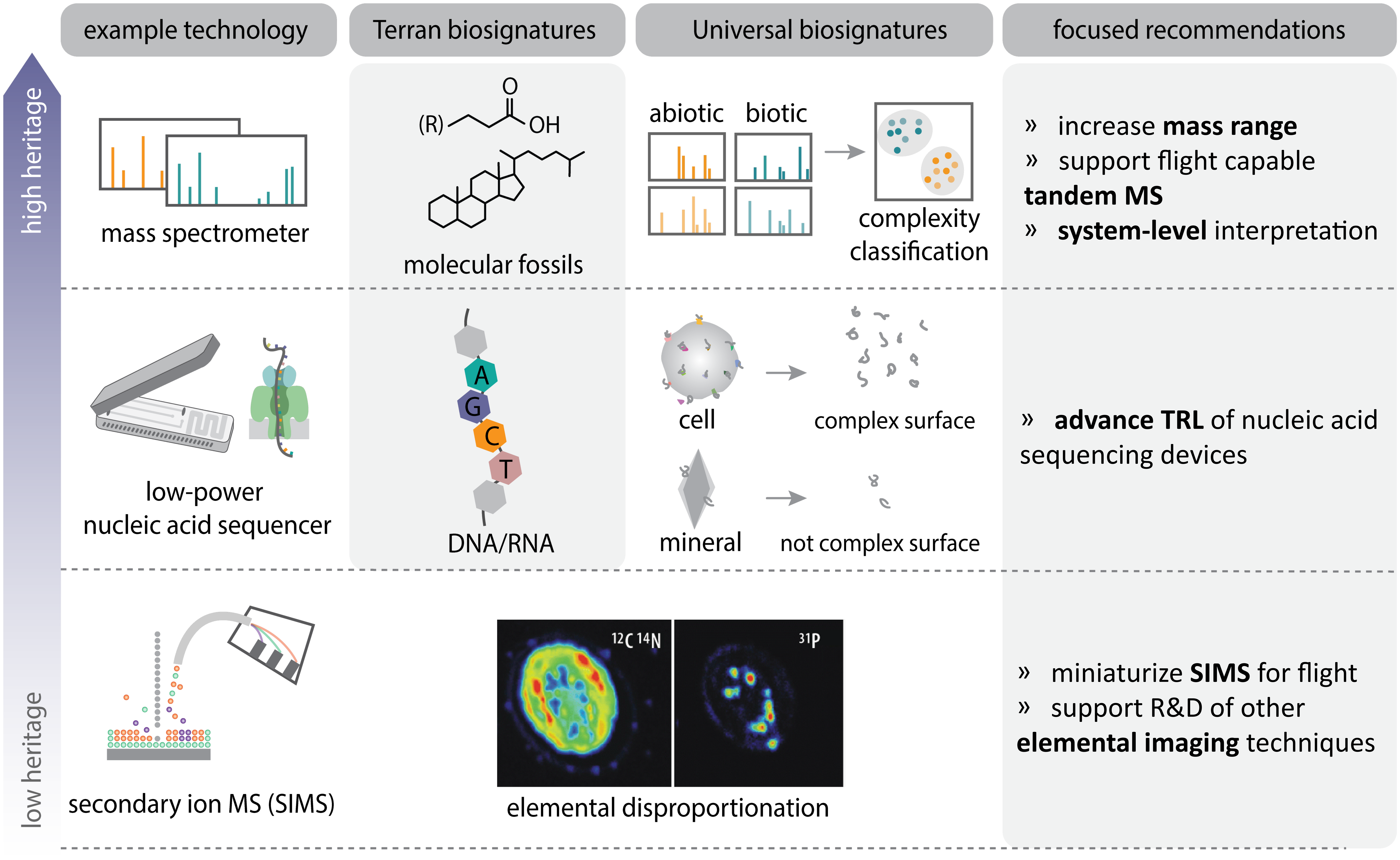

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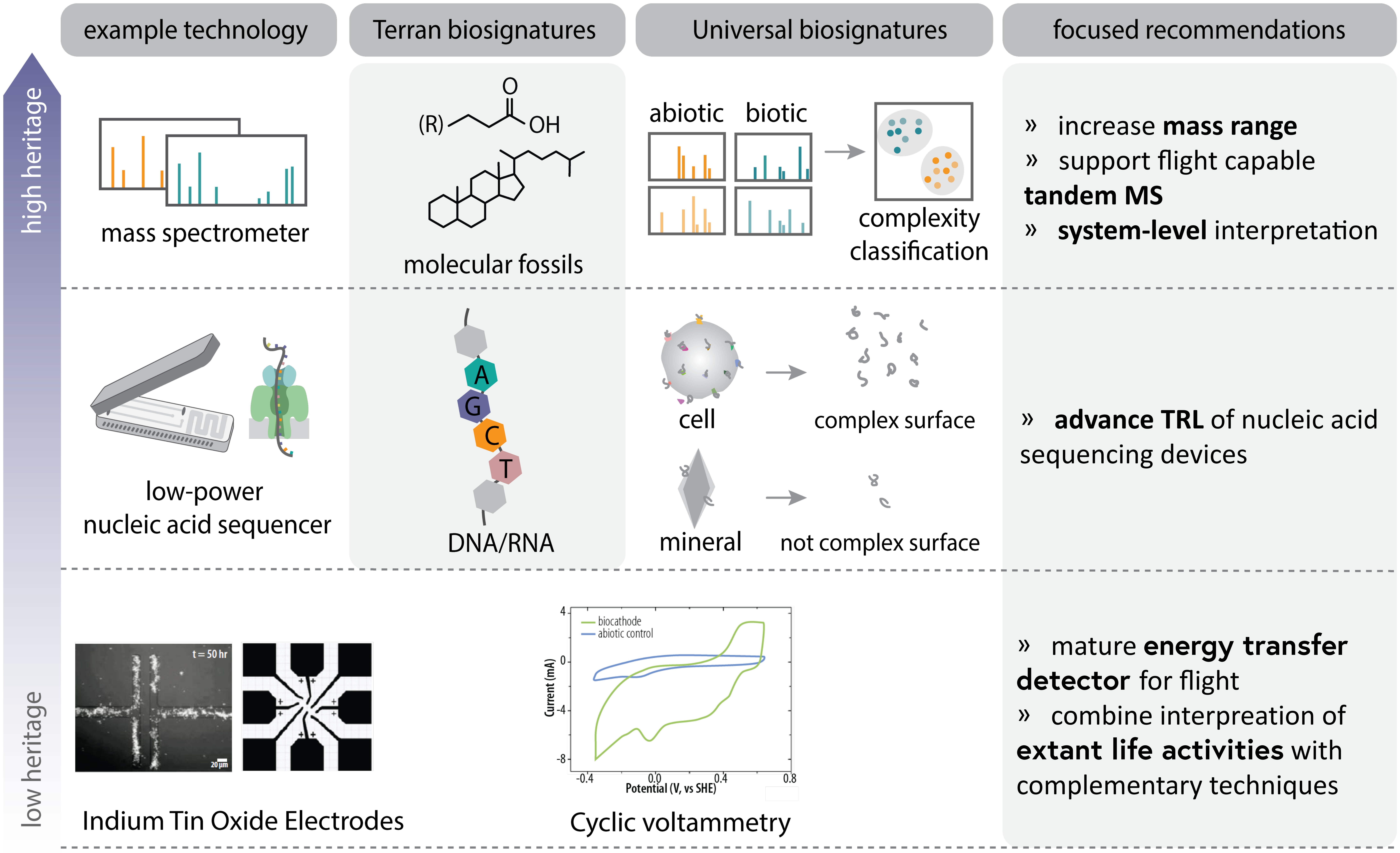
secondary ion MS (SIMS)
^{12}C ^{14}N
^{31}P
elemental disproportionation
» miniaturize **SIMS** for flight
» support R&D of other **elemental imaging** techniques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t = 50 hr
20 µm
Indium Tin Oxide Electrodes
biocathode
abiotic control
Current (mA)
Potential (V, vs SHE)
4
0
-4
-8
-0.4
0.0
0.4
0.8
Cyclic voltammetry
» mature energy transfer detector for flight
» combine interpretation of extant life activities with complementary techniques

RECOMMENDATIONS

Strong and sustained **support of R&A** to develop **universal theories to recognize signatures of life**

Support of a more **diverse program** of **instrument development** and **maturations**

Implementation of a **wider range of complementary *in situ* science measurements** using **robust statistical methods**

Enhancing robustness of life detection strategies

Establish rigorous guidelines for **instrument selection criteria** and **science measurement requirements** informed by:

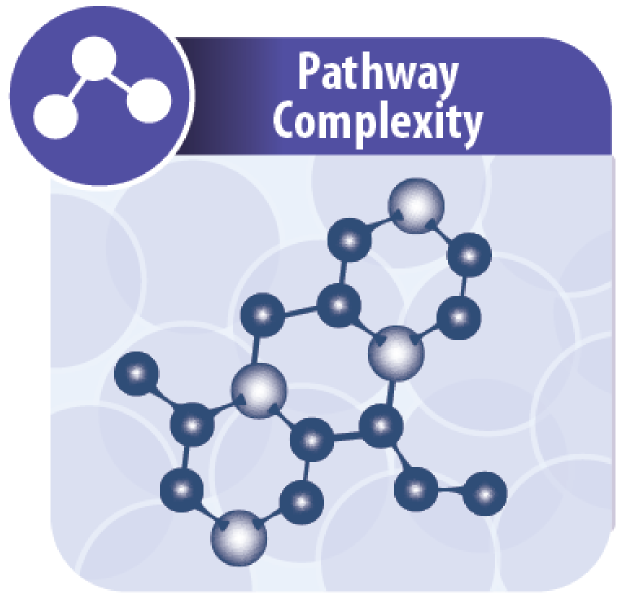
(1) comprehensive **reference sample set**

(2) checks-and-balances approach between scientific measurements

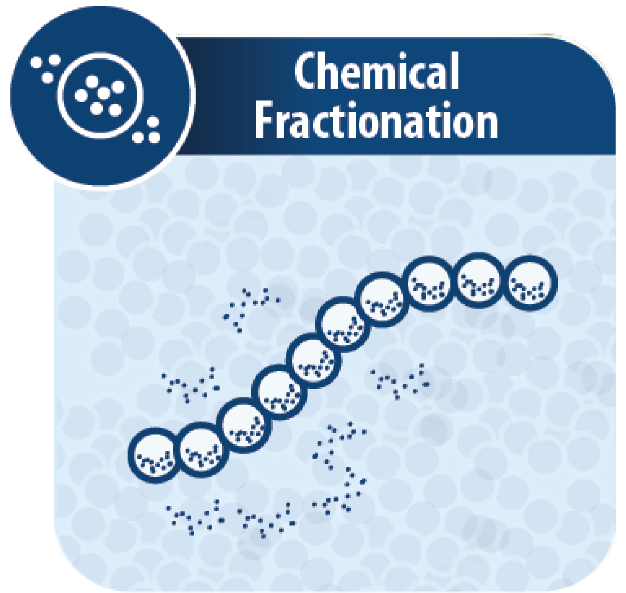
(3) increase knowledge on potential **contaminating signals**

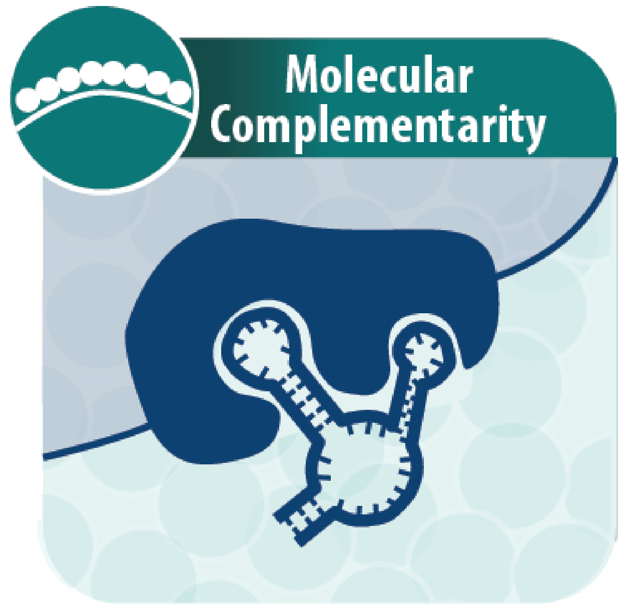
Research into universal features of life that can inform **measurement requirements** and guide **data analysis** and **instrument selection**

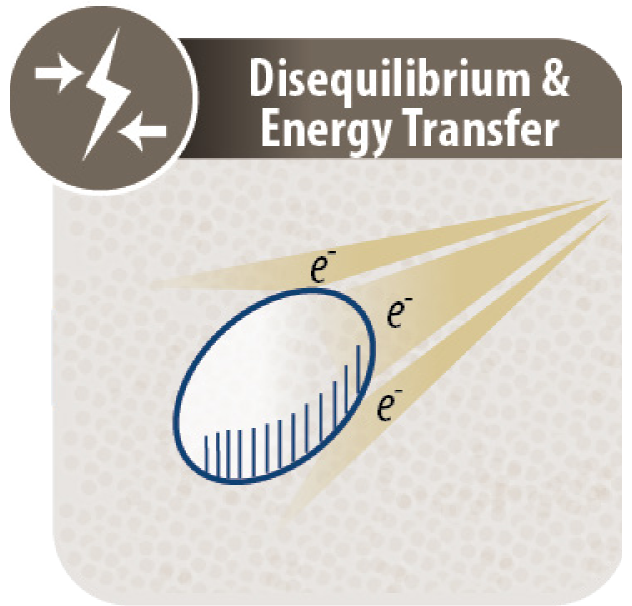
More general approaches to life detection significantly diminishes the potential for **false negative** results



The Laboratory for AGNOSTIC BIOSIGNATURES







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Christopher House, Pennsylvania State University
Peter Girguis, Harvard University
Leroy Cronin, University of Glasgow
Barbara Sherwood Lollar, University of Toronto
Andrew Steele, Carnegie Institution for Science
Pamela Conrad, Carnegie Institution for Science

White Paper submitted to the Planetary Science and Astrobiology Decadal Survey 2023-2032
14 co-authors, 62 co-signatories