# NASA'S FRAMEWORK FOR DETECTING EXTRATERRESTRIAL LIFE

## 10 INFOGRAPHICS • ONE COMPLETE GUIDE

THE SCALES, FRAMEWORKS & SYSTEMS BEHIND THE SEARCH FOR LIFE BEYOND EARTH

NASA uses a comprehensive, multi-layered approach to determine whether extraterrestrial life has been detected. This 10-part infographic series breaks down the essential tools, scales, and frameworks that guide missions from first signal to potential discovery.

## THE 10 TOPICS IN THIS SERIES

1. **CONFIDENCE OF LIFE DETECTION (COLD) SCALE**
   The 7-level scale for communicating how close we are to confirmed evidence of extraterrestrial life.
2. **LADDER OF LIFE DETECTION**
   15 potential features of life, from habitability to Darwinian evolution, ranked by the strength of their evidence.
3. **EIGHT CRITERIA FOR A CONVINCING LIFE-DETECTION CLAIM**
   The essential eight scientific tests every extraordinary claim must satisfy.
4. **BIOSIGNATURE STANDARDS OF EVIDENCE**
   A 2-level, 5-question framework to evaluate detection validity and biological interpretation.
5. **LIFE DETECTION KNOWLEDGE BASE (LDKB)**
   Evaluating biosignatures using chemistry, structure, activity across four evidence dimensions.
6. **CRITERIA FOR BIOSIGNATURE EVALUATION**
   Understanding true positives, false positives, false negatives, and how we minimize uncertainty.
7. **LIFE DETECTION FORUM (LDF)**
   Connecting science, measurements, and technology to turn biosignatures into mission requirements.
8. **PLANETARY PROTECTION CATEGORIES**
   Categories I–V for preventing contamination and protecting both Earth and other worlds.
9. **TECHNOLOGY READINESS LEVELS (TRL)**
   The 1–9 scale for measuring the maturity of life-detection technologies.
10. **HABITABILITY VS. LIFE DETECTION PROCESS**
    From habitable environments to independently confirmed evidence of life.

**SCIENCE. RIGOR. PATIENCE.**
**THE PATH TO DISCOVERY IS BUILT ON EVIDENCE.**

EXPLORING LIFE'S POSSIBILITIES.
EXPANDING HUMAN KNOWLEDGE.

# CONFIDENCE OF LIFE DETECTION (COLD) SCALE

A FRAMEWORK FOR COMMUNICATING HOW STRONG THE EVIDENCE FOR EXTRATERRES*TRIAL* LIFE IS

**7** **ACHIEVE INDEPENDENT CONFIRMATION.**
The detection is independently confirmed by a separate team, instrument, or method.

**6** **TEST AND ELIMINATE OTHER ALTERNATIVE HYPOTHESES WITH FOLLOW-UP OBSERVATIONS.**
Further observations rule out remaining plausible nonbiological explanations.

**5** **FIND AN ADDITIONAL INDEPENDENT BIOSIGNATURE.**
A separate line of evidence for life is detected in the same environment.

**4** **RULE OUT NONBIOLOGICAL EXPLANATIONS.**
All plausible nonbiological processes that could produce the signal are excluded.

**3** **SHOW THE ENVIRONMENT COULD SUPPORT BIOLOGY AND THAT BIOLOGY COULD PLAUSIBLY PRODUCE THE SIGNAL.**
Conditions are suitable for life, and a biological origin for the signal is plausible.

**2** **RULE OUT CONTAMINATION.**
Demonstrate the signal is not caused by terrestrial contamination.

**1** **DETECT A POSSIBLE BIOSIGNATURE SIGNAL.**
An observation hints at something that could be produced by life.

## HOW TO READ THE SCALE

The CoLD Scale levels are stages of evidential confidence, **not percentages.**

Higher levels require more evidence, independent tests, and the elimination of alternative explanations.

## IMPORTANT TO REMEMBER

A finding can be intriguing at Level 1 while still **far from confirmed life.**

**FROM INTERESTING SIGNAL TO CONFIRMED LIFE, CONFIDENCE BUILDS STEP BY STEP.**

**Source:** NASA Astrobiology life-detection resources

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# NASA'S LADDER OF LIFE DETECTION

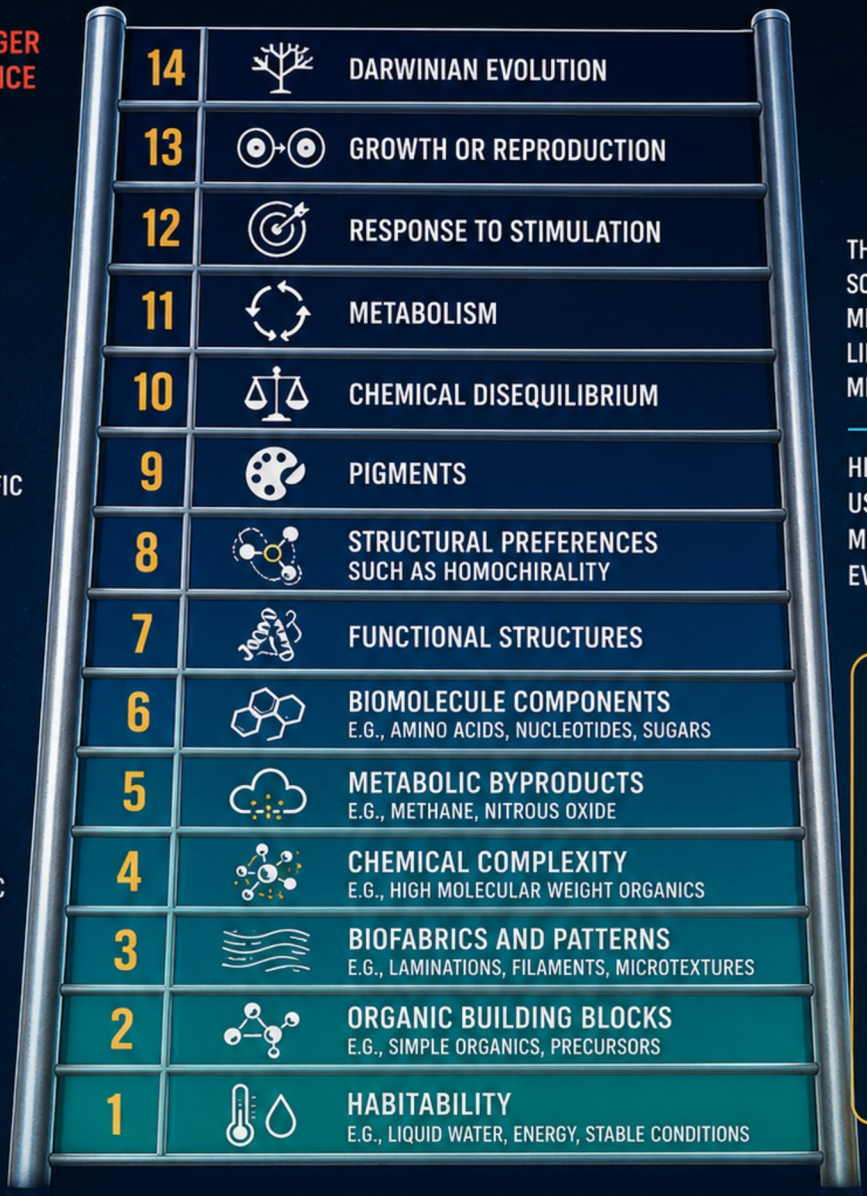
## NOT ALL EVIDENCE FOR LIFE IS EQUALLY PERSUASIVE

STRONGER EVIDENCE

MORE LIFE-SPECIFIC SIGNALS

LESS LIFE-SPECIFIC SIGNALS

WEAKER EVIDENCE




THE LADDER HELPS SCIENTISTS PRIORITIZE MEASUREMENTS FOR LIFE-DETECTION MISSIONS.

HIGHER RUNGS USUALLY REPRESENT MORE LIFE-SPECIFIC EVIDENCE.

**KEY IDEA**

A HABITABLE ENVIRONMENT IS NOT THE SAME AS A LIVING ONE.

## MULTIPLE LINES OF EVIDENCE ARE STRONGER THAN ANY SINGLE SIGNAL.

Source: NASA Astrobiology life-detection resources

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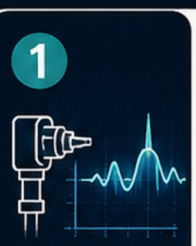
# EIGHT CRITERIA FOR A CONVINCING LIFE-DETECTION CLAIM

ROBUST EVIDENCE. MULTIPLE CHECKS. STRONGER CONCLUSIONS.



## 1 SENSITIVITY

Can the instrument measure the signal well enough?

## 2 CONTAMINATION CONTROL

Can contamination be excluded?

## 3 REPEATABILITY

Can the result be reproduced?

## 4 DETECTABILITY

Could the biosignature be detected in that environment?

## 5 PRESERVATION

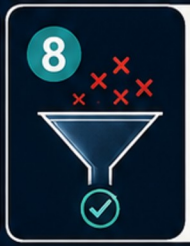
Could the evidence survive until it is measured?

## 6 RELIABILITY

Can it be distinguished from abiotic processes?

## 7 COMPATIBILITY

Is it consistent with plausible biology?



## 8 BIOLOGY AS LAST RESORT

Have nonbiological explanations been exhausted?

## WHY THIS MATTERS

Extraordinary claims need robust evidence and cross-checks.

Applying these criteria helps ensure that a life-detection claim is well supported, credible, and reproducible.

## SCIENTIFIC DISCIPLINE

Convincing life detection depends on **measurement quality** and **interpretation quality.**

MEASURE CAREFULLY

INTERPRET CAREFULLY

CONCLUDE CAREFULLY

Source: NASA life-detection literature

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# BIOSIGNATURE STANDARDS OF EVIDENCE

## A TWO-LEVEL FRAMEWORK FOR INTERPRETING SIGNALS

### LEVEL 1

Establish that the signal is real and correctly identified.

### LEVEL 2

Evaluate whether the signal is best explained by biology.

### LEVEL 1: SIGNAL QUALITY

**1 DETECTION**
Was a real signal detected?

**2 IDENTIFICATION**
Was the signal correctly identified?

### LEVEL 2: INTERPRETATION

**3 ABIOTIC ALTERNATIVES**
Could nonbiological processes make it?

**4 BIOLOGICAL PLAUSIBILITY**
Could life plausibly generate it in that environment?

**5 INDEPENDENT EVIDENCE**
Do other lines of evidence support the biological interpretation?

**INCREASING CONFIDENCE** after each hurdle is cleared.

### IMPORTANT DISTINCTION

**A SIGNAL CAN BE REAL WITHOUT BEING BIOLOGICAL.**

Our goal is to determine the most likely explanation.

### THE ROLE OF FALSE POSITIVES

Every step is designed to reduce the risk of false positives. Confidence increases only as alternatives are tested and evidence converges.

LOW CONFIDENCE — HIGH CONFIDENCE

**DETECTION, IDENTIFICATION, AND INTERPRETATION ARE THREE DIFFERENT HURDLES.**

Source: NASA community biosignature assessment work

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# LIFE DETECTION KNOWLEDGE BASE

## EVALUATING BIOSIGNATURES WITH EVIDENCE AND CONTEXT

The Life Detection Knowledge Base helps scientists compare biological and abiotic explanations for candidate biosignatures using a consistent framework.

## THREE BIOSIGNATURE FAMILIES

### CHEMISTRY
Molecules and elemental patterns that may indicate biological processes.

### STRUCTURE
Organized patterns or forms that may result from life.

### ACTIVITY
Energy use, cycling, or dynamics that may indicate life.

## FOUR EVALUATION DIMENSIONS

### 1. BIOLOGICAL PREVALENCE
How commonly biology produces this signal.

RARE — COMMON

### 2. ABIOTIC PREVALENCE
How commonly abiotic processes produce this signal.

RARE — COMMON

### 3. BIOLOGICAL SIGNAL STRENGTH
How strong and distinctive the biological signal is.

WEAK — STRONG

### 4. ABIOTIC SIGNAL STRENGTH
How strong and convincing abiotic mimics are.

WEAK — STRONG

Higher is better for biology  Lower is better for biology

## HOW IT WORKS

- Evidence is stronger for life when biology commonly produces the signal (high biological prevalence).
- Evidence is stronger when abiotic processes rarely produce the signal (low abiotic prevalence).
- Evidence is stronger when the biological signal is strong and distinctive (high biological signal strength).
- Evidence is stronger when abiotic mimics are weak or indistinct (low abiotic signal strength).

## EXAMPLE COMPARISON

| SIGNAL A (Example) | DIMENSION | SIGNAL B (Example) |
|---|---|---|
| ●●●●○ | Biological Prevalence | ○○●○○ |
| ○○○●○ | Abiotic Prevalence | ●●●●○ |
| ●●●●○ | Biological Signal Strength | ○○●○○ |
| ○○○○● | Abiotic Signal Strength | ●●●○○ |

STRONGER CASE FOR BIOLOGY

Signal A is more consistent with life; Signal B has strong abiotic explanations.

WEAKER CASE FOR BIOLOGY

## BIG QUESTION

**UNDER THESE CONDITIONS, DOES THIS SIGNAL FAVOR BIOLOGY OR CHEMISTRY?**

**Source:** NASA Center for Life Detection resources

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# FALSE POSITIVES VS FALSE NEGATIVES IN LIFE DETECTION

UNDERSTANDING AND MANAGING UNCERTAINTY IN THE SEARCH FOR LIFE

**MISSING LIFE**
False negatives mean life is there—but we didn't detect it.

**OVERSTATING LIFE**
False positives mean we think life is present—but it isn't.

## LIFE DETECTION TRUTH TABLE (2×2)

| | SIGNAL DETECTED (TEST POSITIVE) | NO SIGNAL DETECTED (TEST NEGATIVE) |
|---|---|---|
| **LIFE PRESENT (ACTUAL)** | **TRUE POSITIVE**<br>Life is present, and we detected a signal. | **FALSE NEGATIVE**<br>Life is present, but we failed to detect it. |
| **LIFE ABSENT (ACTUAL)** | **FALSE POSITIVE**<br>Life is absent, but we detected a signal that mimics life. | **TRUE NEGATIVE**<br>Life is absent, and we detected no signal. |

### WHY FALSE POSITIVES CAN OCCUR

Abiotic processes can produce signals that look like life.

- Abiotic chemistry mimics biosignatures (e.g., methane, organics).
- Contamination from spacecraft, instruments, or Earth.
- Instrument noise or artifacts.
- Ambiguous or non-unique biosignatures.

### WHY FALSE NEGATIVES CAN OCCUR

Real life may be missed for many reasons.

- Poor preservation or degradation of biosignatures.
- Signals are too weak or below detection limits.
- Inadequate sampling (wrong place, wrong time).
- Limited instruments or measurements.
- Life uses unfamiliar chemistry or strategies.

### MISSION DESIGN IMPLICATION

Effective life-detection missions reduce both false positives and false negatives.

- Use multiple, independent lines of evidence.
- Sample diverse environments.
- Maximize sensitivity and dynamic range.
- Calibrate, qualify, and validate instruments.

**THE BEST LIFE-DETECTION SYSTEMS MINIMIZE BOTH MISSED SIGNALS AND MISLEADING SIGNALS.**

**Source:** NASA life-detection evaluation frameworks

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# BIOSIGNATURE CLASSES

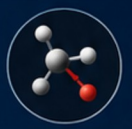
## CHEMISTRY, STRUCTURE, AND ACTIVITY

**NO SINGLE CLASS PROVES LIFE.**

THE STRONGEST CASES COMBINE MULTIPLE LINES OF EVIDENCE.

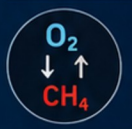
### 1 CHEMISTRY

Molecular and elemental signatures of life



**ORGANICS**
Complex carbon-bearing molecules that can be building blocks of life.

**ISOTOPIC PATTERNS**
Isotopic ratios fractionated in ways commonly associated with biology.




**REDOX DISEQUILIBRIUM**
Coexistence of oxidized and reduced compounds that should react.

**BIOMOLECULE-LIKE COMPOUNDS**
Amino acids, lipids, sugars, nucleotides, or other biologically relevant molecules.

### 2 STRUCTURE

Physical patterns and organization

**CELL-LIKE FORMS**
Discreet compartments with sizes and features consistent with cells.

**TEXTURES**
Filaments, sheaths, mats, or colonies with biogenic-like textures.

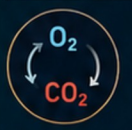
**LAYERS**
Repeated or ordered layering suggestive of biological influence.

**MORPHOLOGY**
Shapes and arrangements that reflect biological organization or engineering.

### 3 ACTIVITY

Dynamic processes that may indicate life

**METABOLISM**
Chemical reactions that convert energy or build biomolecules.



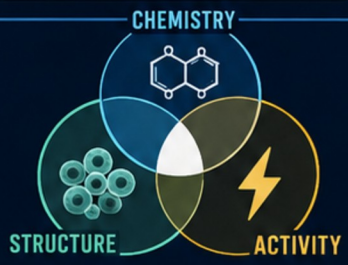

**GAS EXCHANGE**
Production or consumption of gases in patterns consistent with life.

**GROWTH**
Increase in size, biomass, or complexity over time.

**RESPONSE TO STIMULATION**
Detectable changes in response to environmental cues.

### STRONGER WHEN COMBINED

Evidence from multiple biosignature classes that converges on the same interpretation is far more convincing than any single line of evidence.




- Converging evidence reduces ambiguity.
- Multiple independent lines increase confidence.
- The best cases show agreement across chemistry, structure, and activity.

### WATCH FOR FALSE POSITIVES

Chemistry, shapes, and processes can sometimes be produced abiotically.

Geology and hydrothermal processes

Abiotic synthesis (e.g., UV, electrochemistry)

Mineral crystal growth

Gas release from non-biological reactions

Physical erosion and sedimentation

**SOURCE:** NASA LIFE DETECTION KNOWLEDGE BASE CONCEPTS

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# HABITABILITY VS LIFE DETECTION

TWO QUESTIONS. DIFFERENT ANSWERS.

## HABITABILITY

ASKS: **COULD** AN ENVIRONMENT SUPPORT LIFE?

### LIQUID WATER
Solvent for biochemical reactions and transport.

### ENERGY SOURCES
Stellar light, chemical, geothermal, or tidal energy to drive processes.

### ESSENTIAL ELEMENTS
Building blocks such as C, H, N, O, P, S and trace metals.

### SUITABLE TEMPERATURE
Conditions that allow liquid water and stable chemistry.

### REDOX GRADIENTS
Differences in oxidation states that can power metabolism.

### pH RANGE
Neither too acidic nor too basic for complex chemistry.

### ENVIRONMENTAL STABILITY
Sufficient time and protection from extremes to sustain processes.

## LIFE DETECTION

ASKS: **IS** THERE EVIDENCE THAT LIFE IS ACTUALLY PRESENT?

### BIOSIGNATURES
Gases or molecules that may be produced by life (e.g., $O_2$, $CH_4$).

### ORGANIC MOLECULES
Complex carbon compounds that may indicate biological processes.

### STRUCTURES
Morphologies such as stromatolites, microfossils, or cell-like forms.

### ACTIVITY
Ongoing processes or patterns consistent with living systems.

### CONTAMINATION CONTROL
Rigorous planetary protection and clean measurements.

### EXCLUSION OF ABIOTIC ALTERNATIVES
Test non-biological explanations before claiming life.

## CASE STUDY: POSSIBLE OUTCOMES

### HABITABLE BUT LIFELESS
Conditions are right for life, but no evidence of it is found.

### ONCE HABITABLE, NOW STERILE
Past conditions may have supported life, but it is gone.

### INHABITED
Evidence indicates life is present (or was recently present).

## WHY THE DISTINCTION MATTERS

Exploring other worlds is a stepwise process. Missions typically progress from assessing habitability to searching for biosignatures.

FIND A WORLD → ASSESS HABITABILITY → PRIORITIZE TARGETS → SEARCH FOR BIOSIGNATURES → EVALUATE EVIDENCE

★ By separating these questions, we avoid false conclusions and strengthen the search for life beyond Earth.

Source: NASA Astrobiology concepts

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# PLANETARY PROTECTION
## AND THE SEARCH FOR LIFE

RESPONSIBLE EXPLORATION. TRUSTED DISCOVERIES.

Planetary protection helps prevent **forward contamination** of other worlds and **backward contamination** of Earth.

## PLANETARY PROTECTION MISSION CATEGORIES

**CATEGORY I**

### MINIMAL CONCERN
Missions to bodies not considered to be of interest for life detection. Minimal planetary protection requirements.

**CATEGORY II**

### SOME SCIENTIFIC INTEREST
Missions to bodies with some potential for past or present life. Limited planetary protection requirements.

**CATEGORY III**

### FLYBY/ORBITER MISSIONS TO IMPORTANT BODIES
Missions to bodies of astrobiological interest where contact is not planned. Stringent spacecraft cleanliness standards.

**CATEGORY IV**

### LANDER/PROBE MISSIONS TO BODIES WHERE CONTAMINATION MATTERS
Missions that make contact with a body of astrobiological interest. Rigorous control of microbial contamination.

**CATEGORY V**

### SAMPLE RETURN TO EARTH
Missions that return samples to Earth, including unrestricted Earth return and restricted Earth return. Highest level of containment and rigorous curation.

## WHY IT MATTERS FOR LIFE DETECTION

A contaminated mission can introduce Earth microbes to other worlds—or bring them back to Earth—creating false signals that can undermine claims of extraterrestrial life and erode public trust.

**Prevents false positives**
Protects the ability to detect real biological signatures.

**Protects other worlds**
Preserves the potential for indigenous life to exist.

**Protects Earth**
Reduces the risk of harmful exposure from returned samples.

**Protects public trust**
Ensures confidence in our science and exploration.

## TWO GOALS

### PROTECT SCIENCE INTEGRITY
Ensure that our search for life beyond Earth is honest, reproducible, and free from contamination.

### PROTECT ENVIRONMENTS
Safeguard other worlds and Earth from harmful contamination and its potential consequences.

Source: *NASA Planetary Protection*

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# FROM SIGNAL TO CONFIRMED LIFE

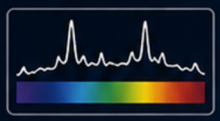
## NASA'S LIFE-DETECTION LOGIC FROM OBSERVATION TO CONFIRMATION

**1**

### ASSESS HABITABILITY

Determine whether the environment could support life as we know it.

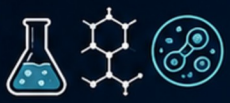
- Liquid water
- Energy sources
- Essential elements
- Stable conditions

**2** 

### SEARCH FOR CANDIDATE BIOSIGNATURES

Look for molecules, patterns, or features that could indicate life.

- Gases
- Organics
- Isotopic patterns
- Morphologies

**3** 

### EVALUATE BIOSIGNATURES USING CHEMISTRY, STRUCTURE, AND ACTIVITY

Check for characteristics expected from living systems.

- Chemical complexity
- Ordered structures
- Metabolic potential
- Dynamic behavior

**4**

### TEST DETECTION QUALITY AND IDENTIFICATION

Ensure the signal is real, well-measured, and correctly identified.

- Instrument performance
- Signal-to-noise
- Reproducibility
- Identification confidence

**5**

### COMPARE BIOLOGICAL AND ABIOTIC EXPLANATIONS

Evaluate whether non-living processes could produce the observation.

- Abiotic plausibility
- Environmental context
- Mechanistic models
- Probability assessment

**6**

### REDUCE FALSE POSITIVES AND FALSE NEGATIVES

Apply controls, tests, and multiple lines of evidence to strengthen the case.

- Controls and blanks
- Multiple methods
- Cross-validation
- Sensitivity analysis

**7**


### PLACE THE EVIDENCE ON THE CoLD SCALE

Rate the confidence from Level 1 (weakest) to Level 7 (strongest).

Levels 1–6: Increasing confidence based on evidence and evaluation.

Level 7: Life detected with strong confidence.

**8**

### SEEK INDEPENDENT CONFIRMATION

Obtain verifying evidence using independent data, methods, or teams.

- Independent observations
- Different instruments
- Separate analyses
- Replication over time

### HOW THE FRAMEWORKS WORK TOGETHER

**LADDER OF LIFE DETECTION (CoLD)**

A 7-level scale that captures increasing confidence in life detection.

**STANDARDS OF EVIDENCE (SoE)**

Criteria for assessing and comparing biological and abiotic explanations at each level.

**LIFE DETECTION KNOWLEDGE BASE (LDKB)**

A living repository of data, experiments, models, and case studies that improves evaluations over time.

Together, these resources guide consistent, transparent, and repeatable life-detection decisions.

## CONFIRMED LIFE REQUIRES CONVERGING EVIDENCE, RIGOROUS TESTING, AND INDEPENDENT VERIFICATION.

Source: NASA Astrobiology life-detection resources

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