This is the story of life in the Universe—or at least the story as we know it so far. As scientists, we strive to understand the environment in which we live and how life relates to this environment. As astrobiologists, we study an environment that includes not just the Earth, but the entire Universe in which we live.

The year 2010 marked 50 years of Exobiology and Astrobiology research at the National Aeronautics and Space Administration (NASA). To celebrate, the Astrobiology Program commissioned this graphic history. It tells the story of some of the most important people and events that have shaped the science of Exobiology and Astrobiology. At now over 60 years old, this field is still relatively young. However, as you will see, the questions that astrobiologists are trying to answer are as old as humankind.

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Special thanks to Heather Graham and Daniella Scalice
The year 2010 marked the 50th anniversary of NASA's Exobiology Program, established in 1960 and expanded into a broader Astrobiology Program in the 1990s. To commemorate the past half century of research, we are telling the story of how this field developed and how the search for life elsewhere became a key component of NASA's science strategy for exploring space. This issue is the eighth in what we intend to be a series of graphic history books. Though not comprehensive, the series has been conceived to highlight key moments and key people in the field as it explains how Astrobiology came to be.

-Linda Billings, Editor
Astrobiology is the study of the origin of life on Earth and the potential for life in the Universe.

The search for life among the stars is as old as humankind.*

Astrobiology underlies our understanding of how life on Earth fits into the Universe, and astrobiology research is the key to NASA’s search for life amongst the stars.

People were questioning life’s potential beyond our planet even when they still thought the Earth was flat.

“to suppose that the Earth is the only populated world in infinite space is as absurd as to believe that in an entire field sown with millet, only one grain will grow.” (1)

But when astrobiologists look for evidence of life in the Universe, what are they looking for?

* See Issue 1

Lindsay Hays (NASA HQ)  Mary Voytek (NASA HQ)

Metrodorus of Chios (Greek School of Atomism, 4th century B.C.)

Issue 8: Biosignatures
Oftentimes, the search for life beyond Earth conjures images of big telescopes listening for signals from distant civilizations, such as Ohio State University’s Big Ear telescope and the Search for Extraterrestrial Intelligence (SETI). (2)

While NASA Astrobiology does not invest in radio SETI today, the program is interested in other forms of technosignatures, such as the detection of artificial heat and light produced by advanced life (3).
The signs of life we look for are called **biosignatures**. Sometimes, specific features are called **biomarkers**.

A biosignature is an object, substance, pattern, and/or activity whose origin specifically requires a biological agent. (4,5)

Useful biosignatures have a high probability that life made them... and a low probability that they were made by ‘non-life.’

In other words, it’s not a ‘false positive.’

David Des Marais (NASA Ames)

Rebecca McCauley Rench (NASA HQ)

Or, if we were really lucky, something like a phone call from space. (3)

Ravi Kopparapu (NASA Goddard)

Hey, could you keep it down over there?

Zorg (Planet Ficticious*)

Many things could be tell-tale signs of life.

Such as molecules made by life, like DNA.

Or elements in a planet’s atmosphere that result from biology.

Like oxygen under certain conditions.

Victoria Meadows (University of Washington Seattle)

Shawn Domagal-Goldman (NASA Goddard)

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Ravi Kopparapu (NASA Goddard)

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*Fictional
Searching for life has always been part of NASA's mission.*

In fact, the first NASA Exobiology project in 1959 was all about biosignatures.**

Ultimately, everything in astrobiology ties back to the goal of identifying life, whether it's ancient life in Earth's geological record...

...or life in extreme environments today. This is a big part of astrobiology research.

I wonder what is in that hot spring... (7)

More recently, NASA formed an entire Research Coordination Network (RCN) specifically focused on how to look for life. (6)

The Network For Life Detection, or NFoLD, includes universities and institutions from all around the USA, and we work with a number of international partners as well.

We start our search on Earth, because our planet holds the only example of life we know of so far.

Extreme environments on Earth give us an idea of the signs of life we might see on certain other worlds.
For instance, Mars is very dry, very cold, and very salty in some places. So we look for places on Earth that are similar to one of these aspects. Like how hydrothermal vents on Earth might help us understand how life might survive in the dark, subsurface ocean of Europa. (8) Or how deep subsurface environments might teach us about the potential for life underground on terrestrial planets like Mars. (9) Then we look at the biosignatures that organisms leave in those environments.

Check out Issue 5 to read more about analog environments on Earth!

- Linda, your friendly neighborhood editor
Some biosignatures could be obvious. Like if we landed a camera on a planet and it spotted Zorg.

Huzzah! Biosignature.

But biosignatures don’t have to be obvious. Even small organisms can have huge impacts if we know what to look for.

On Earth, tiny microbes can build big things like stromatolites.

Even some huuuuge rock formations are tied to life.

These structures can last a really long time. Like billions of years.

This means that the structures actually last much longer than the organisms that made them.

Even some huuuuge rock formations are tied to life.

Dover, England.

Pieces of once-living organisms can be a big component of sedimentary rocks like limestone...
In general, biosignatures and habitable environment signatures can be grouped into ten broad categories. (10)

We could look for biomolecules...

...minerals...

textures...

...there are many options.

As a first step, NASA Astrobiology developed the Ladder of Life Detection to help us think about how to detect life within the practical constraints of space missions. (11,12)

Right now a lot of the instruments we need are too big to send on a space mission.

Which is a good reason to bring a sample back.

As long as we consider planetary protection, but more on that later.

Marc Neveu (NASA Goddard)
So far, there isn’t macroscopic life – or life we can see with the naked eye – on the surfaces of worlds in our system.

We quickly found out that it wouldn’t be so easy.

The search for life beyond Earth relies on data from probes in our solar system, or astronomical observations.

Nyet. No Plants.

Hey, there is some sort of liquid on Titan! Craaazzzy!

Don’t see any life... but what is under Europa’s icy shell?

Hey, Pluto has mountains!

But there are still places we haven’t looked. And microscopic life is still a possibility.

And rocks could still contain biosignatures of ancient life.

In the 90’s, a big thing happened with a little ‘rock’ from Mars.
ALH84001 is a fragment from a martian meteorite that was found in the Allan Hills of Antarctica in 1984.

Are those microfossils in this meteorite? (13)

Scientists may have found signs of ancient life on Mars!

Wait! We need more evidence! (14)

The microscopic features in ALH84001 were interesting...

...but too small to hold some basic structures that we think living cells need.

With more study, scientists revealed ways that the features could be made with chemistry alone. It was a powerful learning opportunity.

ALH84001 showed us that biosignature studies need to be multidisciplinary, and changed the way we search for life. (15)

The search became 'habitability assessment,' and required disciplines like geology, astrobiology, atmospheric science...

After all, missions must be multidisciplinary to get the biggest science return for the cost.

Rather than looking for evidence of specific life forms, we started looking for environments that life could have survived in.

This does look like a dried up river delta on Mars...

For a time, we focused on the idea, 'follow the water.'
Both Jupiter and Saturn have moons that are thought to have oceans of water beneath their icy surfaces.*

Astrobiologists also look for exoplanets that might be able to host liquid water.**

And they look back at Earth, both from space and in geological time, as an example of a watery world.**

But drilling deep below ground and preparing samples for a microscope are difficult things for a robot. Technology is getting smaller, but we still need a whole lab to look for microbial life in samples from a place like Mars.

Habitability assessment has helped us narrow down where to look... and now we're getting ready to specifically look for life again.

That's why we're so excited about the next step...

Missions didn't only look for water on Mars... they looked EVERYWHERE! And they found it.

There totally used to be a hydrothermal vent here...

Hey, I think there could've been fresh, flowing water here. And it seems kind of gassy over there...

Hubble Space Telescope

Deep Impact/EPOXI (NASA)

Curiosity Rover, Mars Science Laboratory (NASA)

Opportunity Mars Exploration Rover (NASA)
Right now, the Mars 2020 Perseverance rover is collecting samples that will be brought back to Earth for Mars Sample Return.*

In labs on Earth, scientists will then look at the samples using powerful instruments that cannot be flown on space missions.

And many different scientists from different fields can work on the same sample.

We've spent a lot of time now characterizing microbial fossils from ancient geological formations on Earth...

...and perfecting our skills for when MSR brings back pieces of Mars.

It's tricky because microbial fossils aren't like, say, dinosaurs.

Right, microbes don't have bones... or any tough parts that can be preserved. We can 'see' ancient microbes based on marks they left in the rock record.

So, they leave markers... kind of like a dinosaur footprint instead of an actual skeleton.

*MSR, See Issue #2
Life as we know it uses water and carbon chemistry. Even single-cell organisms have molecules that only life makes, like DNA.

“Carbon chemistry provides a tool for identifying extant and extinct life on Earth and, potentially, throughout the Universe.” (18)

Sometimes, the specific identifiable features are called ‘biomarkers.’ Biomarkers are a signal that a process is happening. In medicine, a biomarker can say ‘this disease is happening right now.’ In medicine, we use biomarkers in your body to diagnose certain illnesses. It’s a similar idea. Say ‘Ahhh.’

A fossil is a biomarker because it is an indication that life was there. Astrobiologists sometimes look at things happening now in order to understand “deep time” or things WAAAAAY in the past.

Chemical biomarkers can tell us how long ago a process evolved. For instance, these iron-bearing rocks needed oxygen in the atmosphere to form.

So microbes that produced that oxygen by photosynthesis must have been around too.
So we don’t find a direct fossil of microbes. But we find markers or signatures of their existence. ‘Biomarker’ is a term used more in the medical community. ‘Biosignature’ is used more by the search for life community.‘Biomarker’ is a term used more in the medical community. ‘Biosignature’ is used more by the search for life community.

Check this out... Hmm... hydrocarbon shapes...

But we use some similar tech... *Gas Chromatography-Mass Spectrometry*

'Biosignature' is used more by the search for life community.

Almost any time we send a mission to space there are planetary protection considerations.

Biosignatures are also super important in Planetary Protection.

Almost any time we send a mission to space there are planetary protection considerations.

Biosignatures are also super important in Planetary Protection.

Before we launch a rover to Mars, or a Dragonfly to Titan... we have be certain we’re not sending any microorganisms or even some molecules, along for the ride. (19)

Contamination could harm Mars, and it could also mess up our search for biosignatures...

So we use every technique we can to make sure mission components are as sterile as possible.

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So we use every technique we can to make sure mission components are as sterile as possible.
Astrobiologists are looking for any life at all, past or present.

The question we ask when exploring worlds isn’t only ‘Is life here right now?’

... whereas humans learned to use things that might make technosignatures, like agriculture or radio, only in the last few millennia or centuries.

We’ll look for biosignatures in samples that MSR brings back...

... but first we have to make sure MSR isn’t bringing any biological contamination with it.

What if we thought that we detected Mars life, but it was actually something we brought with us? That ‘false positive’ could complicate our search for life.

Because the contamination could cause a ‘false positive.’

We could mistake Earth microbes for modern Mars life, or Earth life could produce compounds that look like ancient biosignatures.

The best biosignatures are things that last through deep time.

If you only look for life that exists right now, that’s a split second in history.

There is a bigger question: ‘Was life ever here?’

Think about how microbes have been on Earth for billions of years...

The question we ask when exploring worlds isn’t only ‘Is life here right now?’
It's like... if there is life in an environment now, then there was probably life there in the past. The opposite isn't necessarily true. Mars might not have life today, but it could have in its past.

If you look for present life on Mars, you miss billions of years of history where life might have been.

Some biosignatures stand up to time better than others.

For instance, your DNA would be a great way to identify you, but it's easy to destroy when it's outside of your body...

...so it usually doesn't last very long after you're gone.

The same isn't true for other molecules, like lipids.

Your cholesterol is unlike other living things, so it can identify you specifically.

Huh, what a thing to be remembered for...

One part of you that could last billions of years is cholesterol.

Cholesterol is a lipid, and lipids don't break apart easily. But parts of lipids are different between different organisms.
Like oil, it lasts a long time because it's hard to break down. That is why oil spills are a problem.

You wouldn't get a 'DNA spill' because DNA is broken down so fast in the environment.

Hmm... needs salt.

DNA breaks down in lots of environmental conditions... and it's good food for microbes.

What does this stuff taste like?

There are also things about lipids that would make them useful in systems that are different than life as we know it on Earth.

The complexity, and distinct carbon isotopic values, might tell you a lipid is a biosignature.

Let me check your cholesterol!! No!

Life also takes advantage of aspects of chemistry, like the three-dimensional qualities of organic chemicals.
Life can also cause certain isotopes of a molecule to be present (or absent)... or an unnatural distribution of certain compounds. (20)

These are other features that could be biosignatures.

In the study of chemometrics, we combine chemical analysis and information science.

We can look for patterns that are unique to specific materials. And ultimately, we might find things that can ‘fingerprint’ materials from life.

For instance, can carbon isotopes be used as “fingerprints” to tell us where organic molecules came from? (21)

Speaking of fingerprints... Oops, I should wash this off.

Some molecules exist in mirror-image pairs, so you have a ‘left’ and a ‘right’ version of the same molecule.

These are called enantiomers, or chiral molecules.

Life can also cause certain isotopes of a molecule to be present (or absent)... or an unnatural distribution of certain compounds. (20)

Whoa those are small scale differences.

Eight neutrons... Carbon-14...7,8, 9, 10... This isotope isn’t found in nature.

Eric Anslyn (University of Texas at Austin)
David Hoffman (UT Austin)
Cornelia Rasmussen (UT Austin)

But life can shift that balance.

In nature many of these molecules would be present in both forms in equal amounts.

We call this ‘enantiomeric excess’ and it could be a biosignature.

We can look for patterns that are unique to specific materials.

And ultimately, we might find things that can ‘fingerprint’ materials from life.

For instance, can carbon isotopes be used as “fingerprints” to tell us where organic molecules came from? (21)

Speaking of fingerprints... Oops, I should wash this off.
We can even consider chemistries that are different than life on Earth. Like, what if life used something other than nucleic acids...

...or reversible bonds, which could allow information transfer in a totally different way than DNA? (23)

Cole Mathis, Santa Fe Institute

Lee Cronin, University of Glasgow

We also might use sequencing technology to fingerprint patterns of surface complexity.

Soon, this technology could be portable enough for a space mission.

We look at how many different kinds of DNA pieces bind to a surface as a way to understand binding site diversity. (22)

That touches on an important topic... how do we detect life 'as we don't know it.'

It might be good to look at biosignatures in an even more general way.

With mathematics and statistics...

And probability.

NASA Astrobiology supports the Laboratory for Agnostic Biosignatures (LAB) that is dedicated to this type of work.

NASA Goddard, Austin

The LAB effort includes scientists from ten intuitions and, of course, we're a member of NFoLD*.

*See page 5

The University of Georgia

Umeå

Glasgow

University Park

Cambridge, MA

Washington, DC

Georgetown

NASA Goddard

Austin

Santa Fe

We look at how many different kinds of DNA pieces bind to a surface as a way to understand binding site diversity. (22)
We can look at things that might be expressions of life in an environment...

...like molecules...

...or macroscopic structures...

Organisms are in constant response to the environment.

There is so much life around us on Earth that it’s hard not to make assumptions about what we’re looking for.

But we can think about life mechanistically. How and why does life produce something we can detect?

And then we ask, ‘does life need this thing to exist in the environment?’

Life is that extra ‘push’ of energy needed in a specific environment to make a specific expression.

Then you look at the environment and figure out if the thing could be made without life.

If the energy required is more than you can get from the environment alone, then you might have a biosignature.

...like buildings or anything else that looks like it took energy to make.
Life produces complex molecules that cannot form randomly. So we developed a molecular complexity index, where we can identify molecules that are too complex to exist in a certain environment without life. We've been developing a framework for looking for life based on probability. We need a signature that is exclusively associated with all life. Environmental context is essential in determining the complexity threshold. And we need a detection system for it. (24)

So we thought...
...can we distinguish between non-living and living systems through complex molecules?

Life produces complex molecules that cannot form randomly.

And we figured out how to test our ideas of complexity in the lab.

So we developed a molecular complexity index, where we can identify molecules that are too complex to exist in a certain environment without life.

Environmental context is essential in determining the complexity threshold.

...can we distinguish between non-living and living systems through complex molecules?

What is the probability of a signature being made with and without life?
Two, determine how signatures of life are generated and preserved in environments similar to the one we're interested in. These methods can help us look for life elsewhere, and can also help us look for life in Earth's past. And identify things we might have otherwise missed.

Agnostic biosignatures take things to the next level. Agnostic methods are not dependent upon our specific knowledge of life on Earth. These methods can help us look for life elsewhere, and can also help us look for life in Earth’s past. And identify things we might have otherwise missed.

So the main goals? One, determine the habitability of an environment (past or present).

Agnostic biosignatures take things to the next level. Agnostic methods are not dependent upon our specific knowledge of life on Earth. These methods can help us look for life elsewhere, and can also help us look for life in Earth’s past. And identify things we might have otherwise missed.

Atacama Desert, Chile

Two, determine how signatures of life are generated and preserved in environments similar to the one we're interested in.

Three, study how non-biological processes might generate the signatures we see.
We want to avoid ‘false positives’ so that we don’t have another Viking or ALH84001.*

We need cooperation across disciplines so that we can agree when we do find something. For a definitive detection of life we will need multiple lines of evidence from multiple scientific disciplines. (27)

But we need to be careful.

We need everyone participating to build up the evidence. (26)

It’s not only about good science, it’s also about being a good colleague. We have to work together.

Studying biosignatures is an entirely interdisciplinary endeavor that needs physical scientists, modelers, biologists, and many other disciplines.

Okay who’s ready?

James Green (NASA HQ)

*See Page 10
Further Resources and References cited in this issue:

6. Astrobiology@NASA, https://astrobiology.nasa.gov/research/astrobiology-at-nasa/
16. NASA (2020) PIA23976. This map shows regions in and around Jezero Crater on Mars, the landing site of NASA's Perseverance rover. The green circle repre-
resents the rover’s landing ellipse. Credit: NASA/JPL-Caltech/USGS/University of Arizona


19. NASA’s Dragonfly mission is part of the New Frontiers Program. For more information, see: https://astrobiology.nasa.gov/missions/dragonfly/


