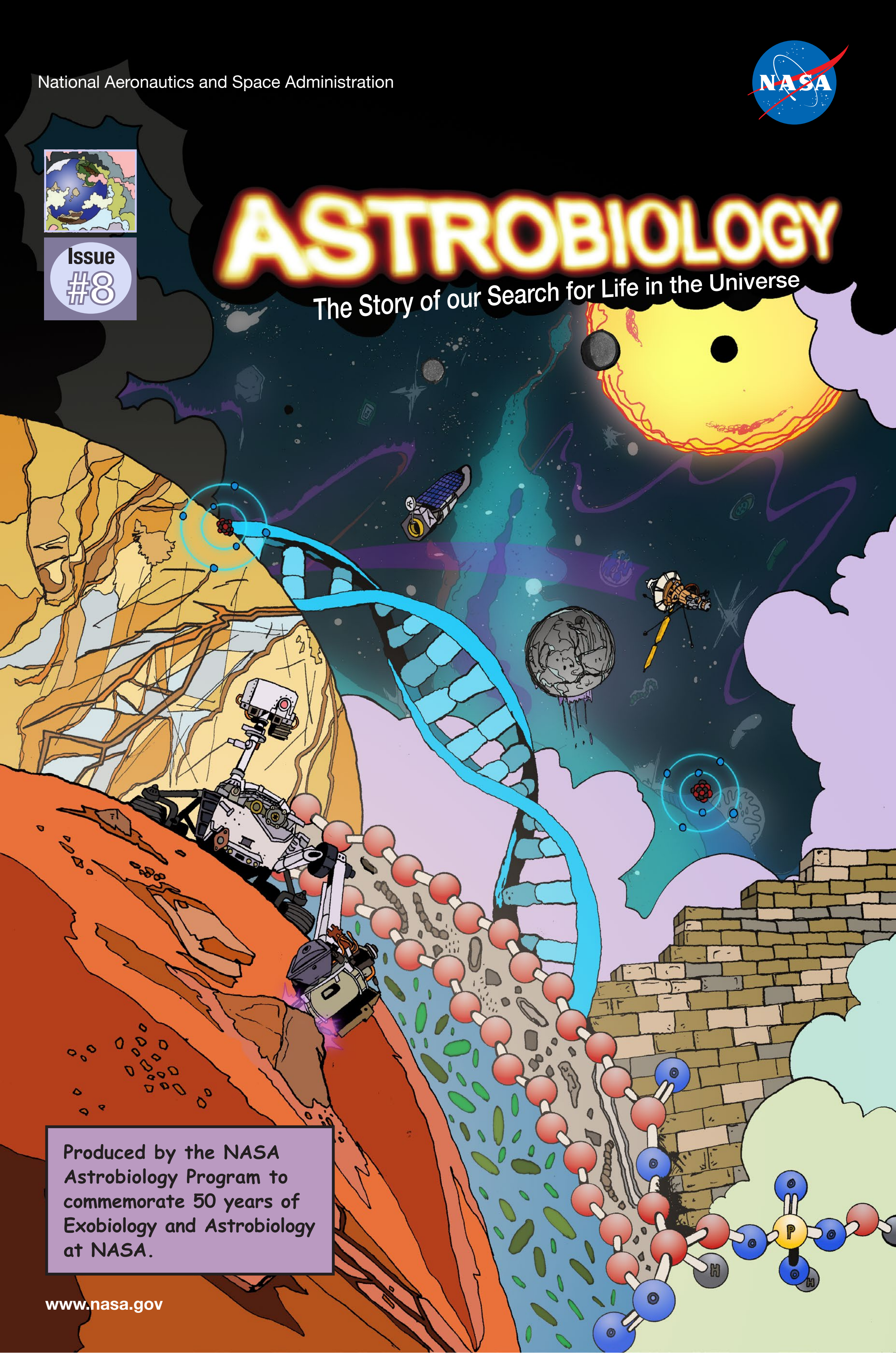
National Aeronautics and Space Administration

ASTROBIOLOGY

The Story of our Search for Life in the Universe

Issue #8



Produced by the NASA Astrobiology Program to commemorate 50 years of Exobiology and Astrobiology at NASA.

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Astrobiology

A History of Exobiology and Astrobiology at NASA

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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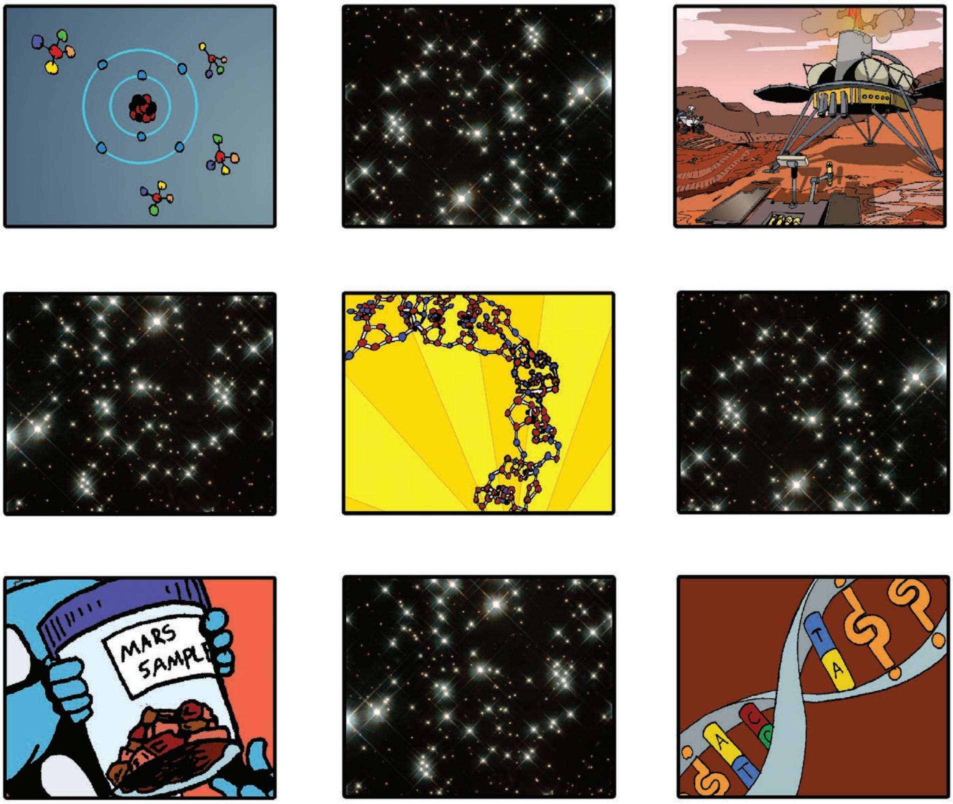
First Edition

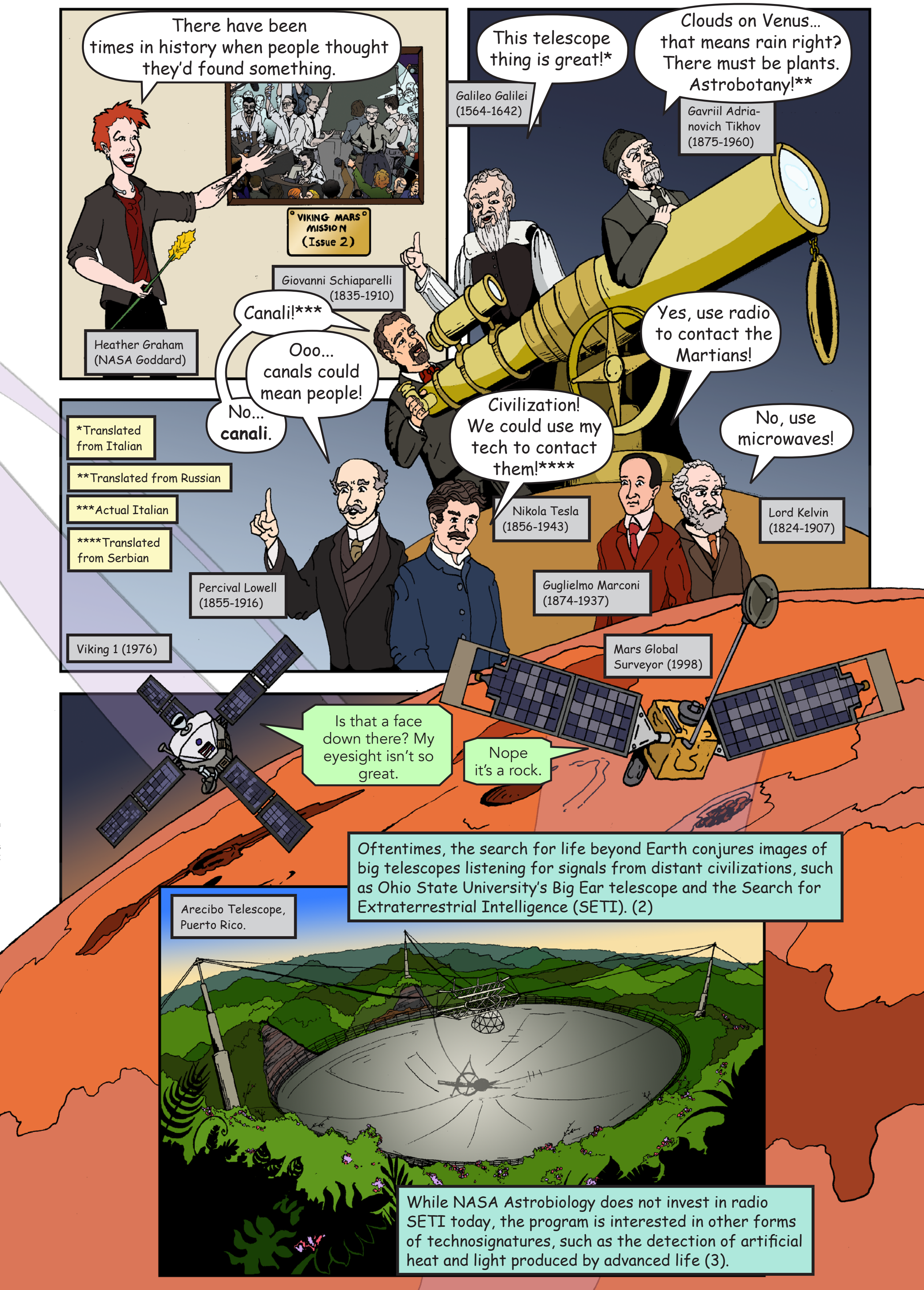
Issue #8—Biosignatures



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.

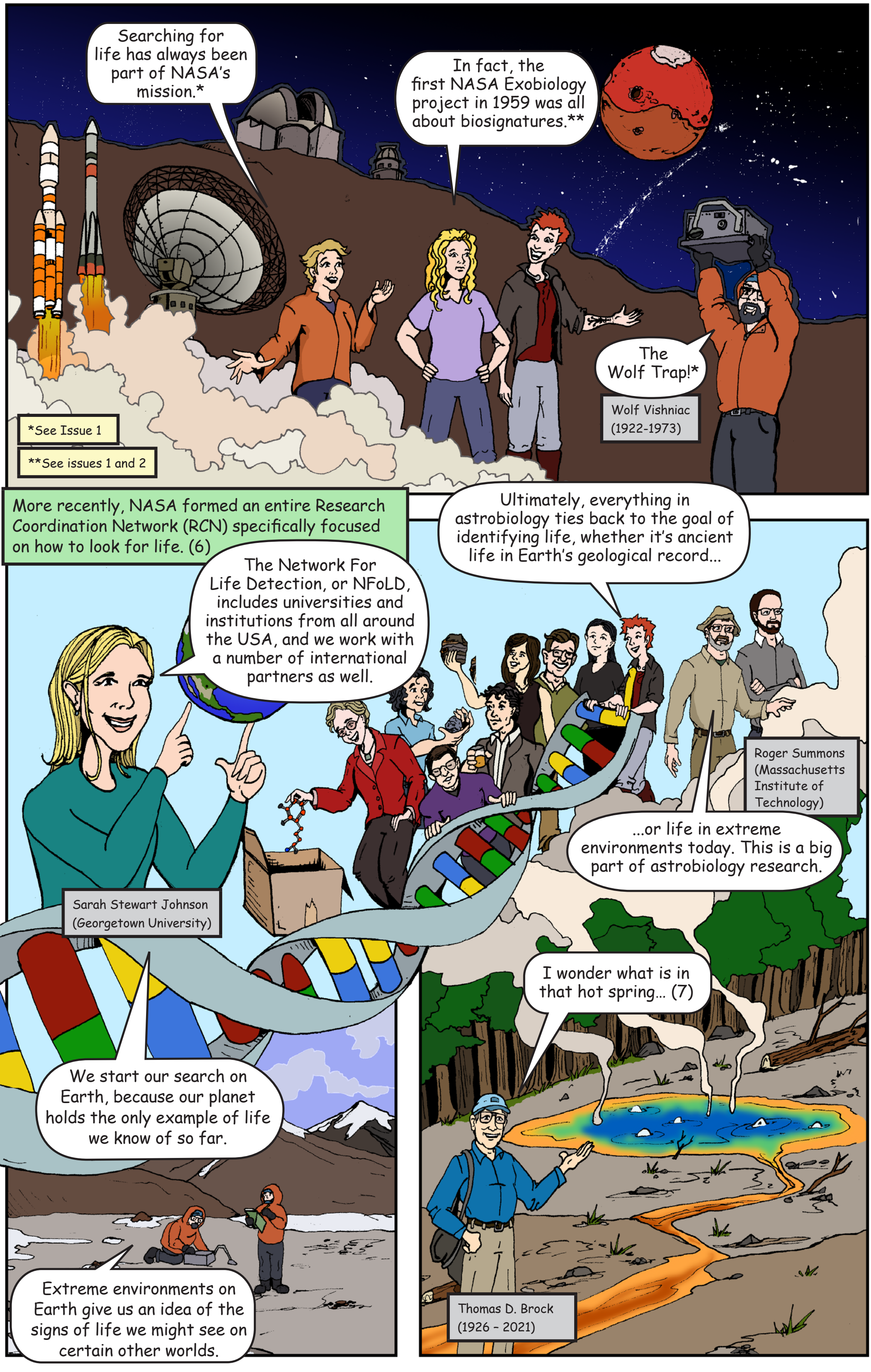
-Linda Billings, Editor


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.*
People were questioning life's potential beyond our planet even when they still thought the Earth was flat.
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.
"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?
Lindsay Hays (NASA HQ)
Mary Voytek (NASA HQ)
Issue 8: Biosignatures
Metrodorus of Chios (Greek School of Atomism, 4th century B.C.)
* See Issue 1

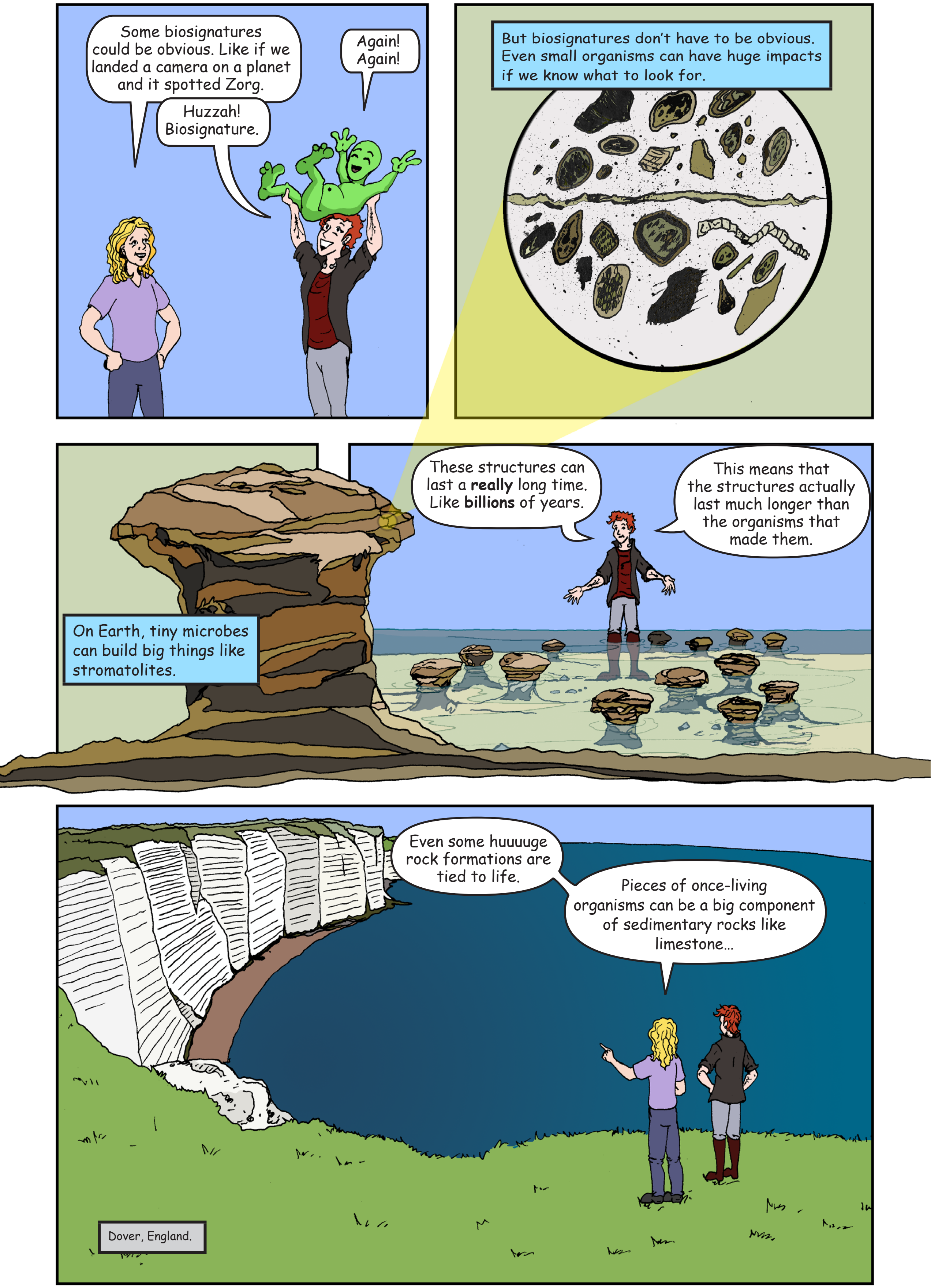


There have been times in history when people thought they'd found something.
VIKING MARS MISSION (Issue 2)
Heather Graham (NASA Goddard)
This telescope thing is great!*
Galileo Galilei (1564-1642)
Clouds on Venus... that means rain right? There must be plants. Astrobotany!**
Gavriil Adria-novich Tikhov (1875-1960)
Giovanni Schiaparelli (1835-1910)
Canali!***
Ooo... canals could mean people!
No... **canali**.
Yes, use radio to contact the Martians!
Civilization! We could use my tech to contact them!****
No, use microwaves!
*Translated from Italian
**Translated from Russian
***Actual Italian
****Translated from Serbian
Nikola Tesla (1856-1943)
Lord Kelvin (1824-1907)
Percival Lowell (1855-1916)
Guglielmo Marconi (1874-1937)
Viking 1 (1976)
Mars Global Surveyor (1998)
Is that a face down there? My eyesight isn't so great.
Nope it's a rock.
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)
Arecibo Telescope, Puerto Rico.
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).

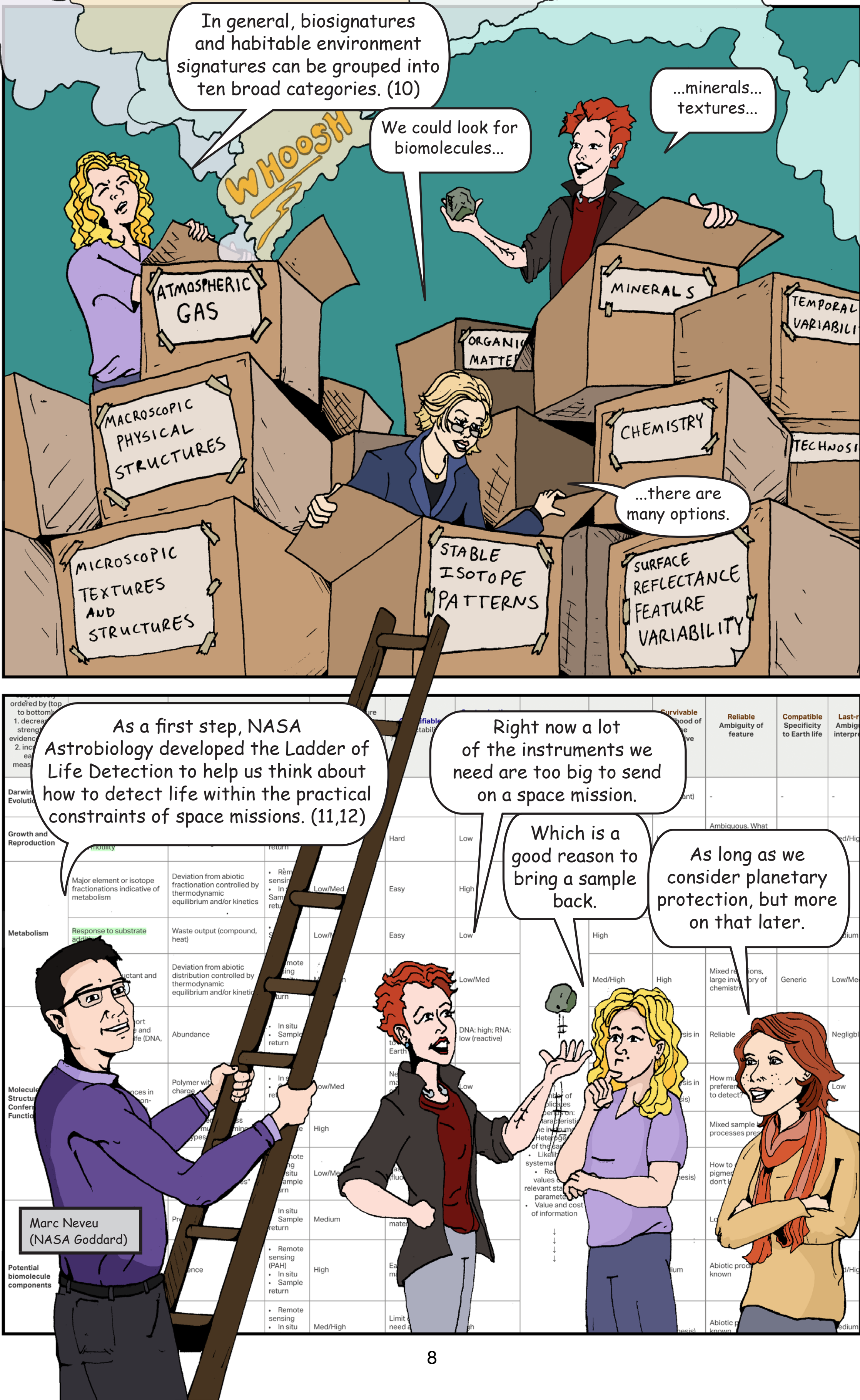
The signs of life we look for are called **biosignatures**. Sometimes, specific features are called **biomarkers**.
A biosignature is an object, substance, pattern, and/or activity whose origin specifically requires a biological agent. (4,5)
Useful biosignatures have a high probability that life made them... and a low probability that they were made by 'non-life.'
David Des Marais (NASA Ames)
Atmospheric Signatures
CHEMICAL DISEQU.
LUNAR SAMPLES
FOSSILS?
In other words, it's not a 'false positive.'
Rebecca McCauley Rench (NASA HQ)
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.
Victoria Meadows (University of Washington Seattle)
Like oxygen under certain conditions.
STERANES
Or, if we were really lucky, something like a phone call from space. (3)
Shawn Domagal-Goldman (NASA Goddard)
Ravi Kopparapu (NASA Goddard)
RING!
RING!
Hey, could you keep it down over there?
Zorg (Planet Ficticious*)
*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.**
The Wolf Trap!*
Wolf Vishniac (1922-1973)
*See Issue 1
**See issues 1 and 2
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.
Sarah Stewart Johnson (Georgetown University)
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.
Ultimately, everything in astrobiology ties back to the goal of identifying life, whether it's ancient life in Earth's geological record...
Roger Summons (Massachusetts Institute of Technology)
...or life in extreme environments today. This is a big part of astrobiology research.
I wonder what is in that hot spring... (7)
Thomas D. Brock (1926 – 2021)

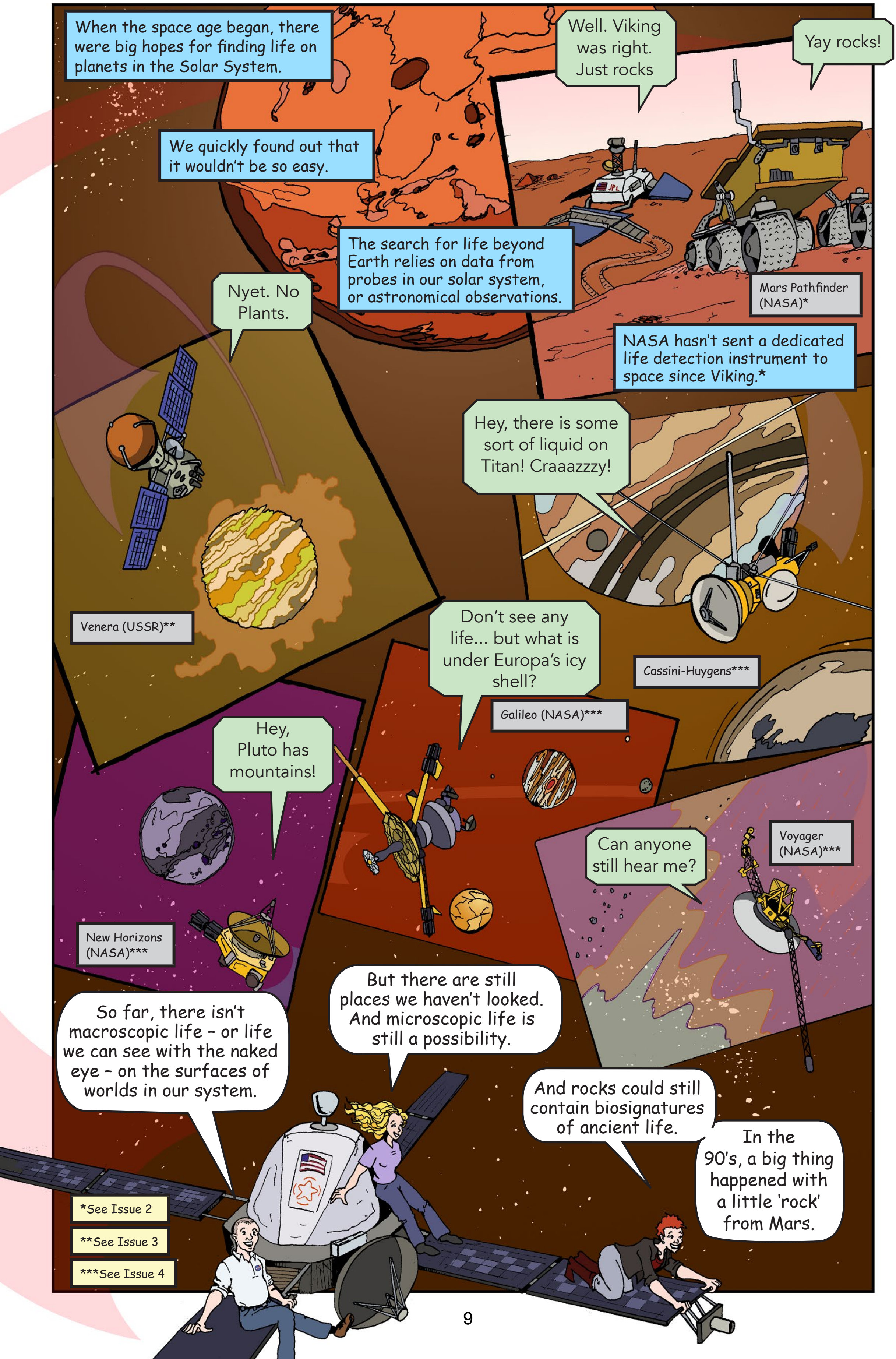

For instance, Mars is very dry, very cold, and very salty in some places.
So we look for places on Earth that are similar to one of these aspects.
DRY VALLEYS - ANTARCTICA
Then we look at the biosignatures that organisms leave in those environments.
Mitch Schulte (NASA HQ)
Like how hydrothermal vents on Earth might help us understand how life might survive in the dark, sub-surface ocean of Europa. (8)
Or how deep subsurface environments might teach us about the potential for life underground on terrestrial planets like Mars. (9)
John Baross (UW Seattle)
Tullis Onstott (1955-2021)
Check out Issue 5 to read more about analog environments on Earth! - Linda, your friendly neighborhood editor

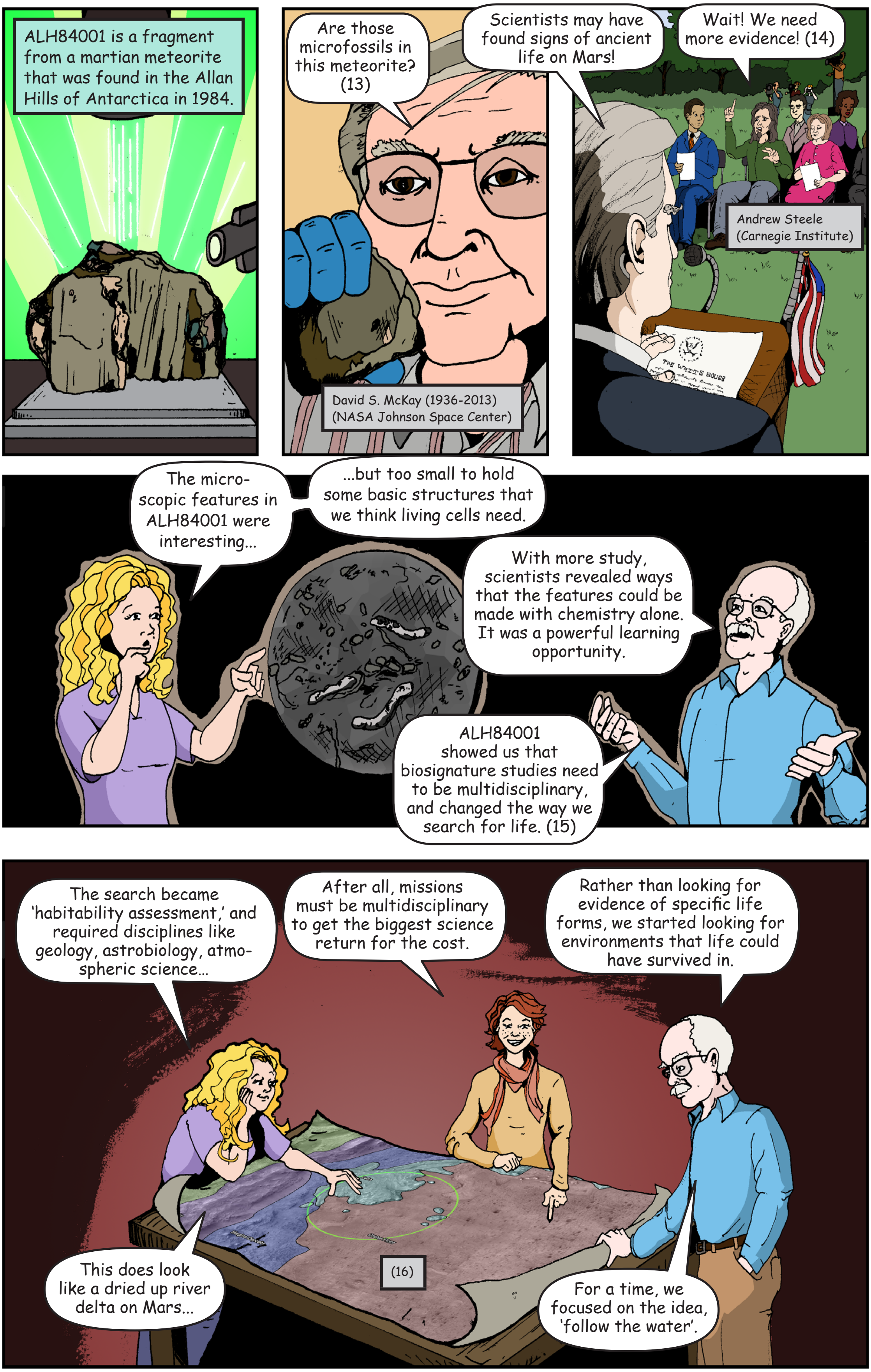


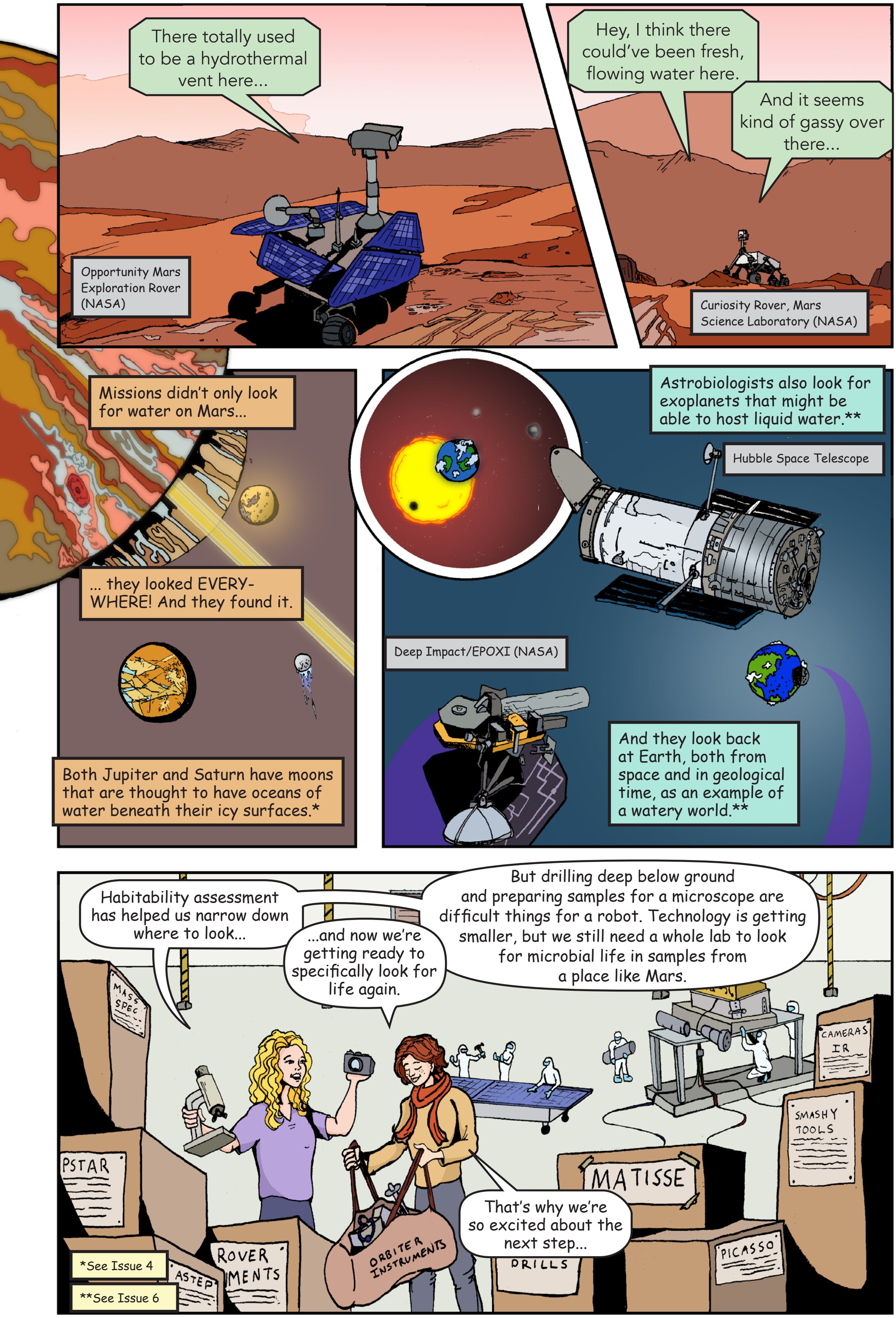
Some biosignatures could be obvious. Like if we landed a camera on a planet and it spotted Zorg.
Huzzah! Biosignature.
Again! Again!
But biosignatures don't have to be obvious. Even small organisms can have huge impacts if we know what to look for.
On Earth, tiny microbes can build big things like stromatolites.
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.
Pieces of once-living organisms can be a big component of sedimentary rocks like limestone...
Dover, England.

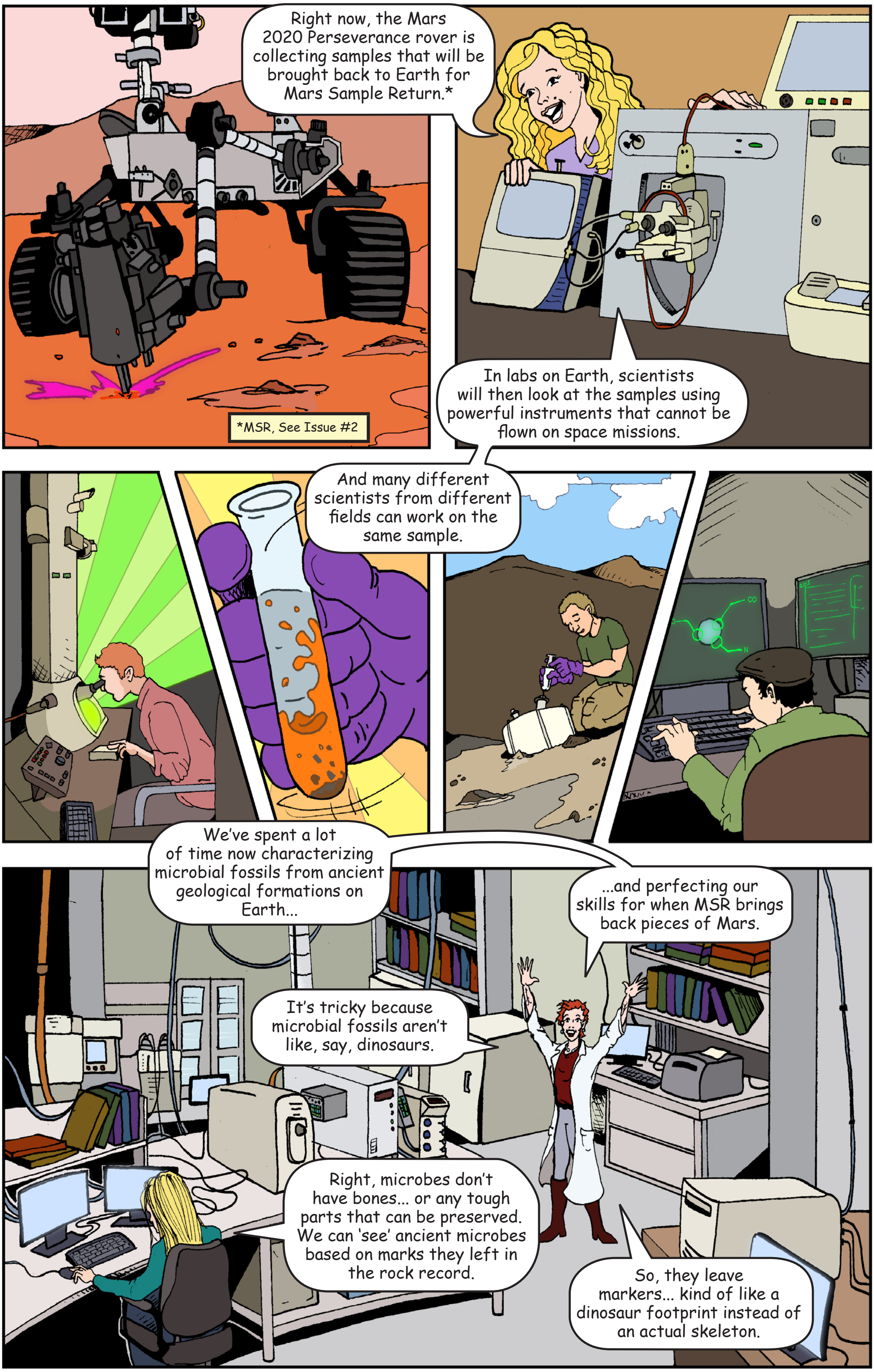


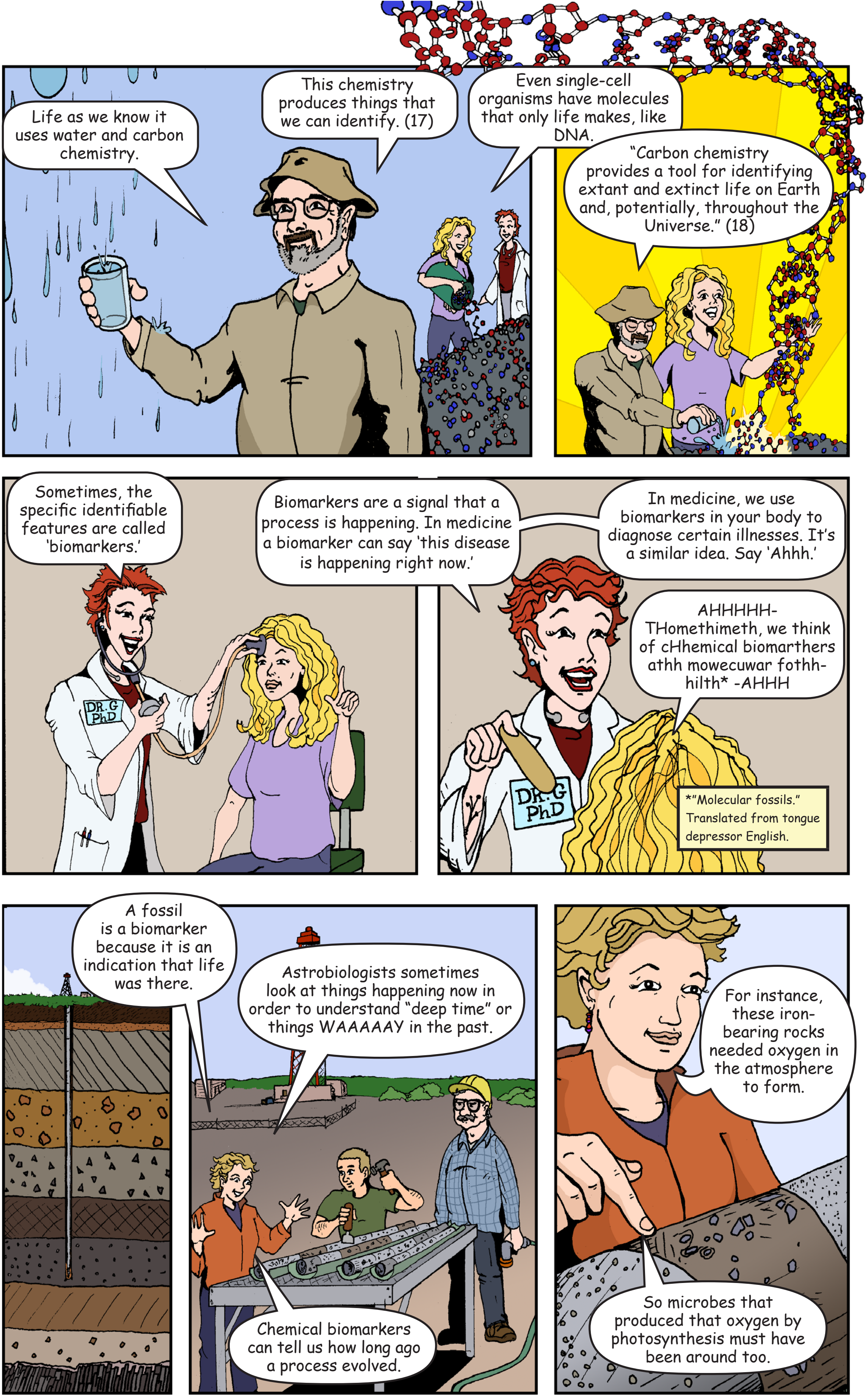
In general, biosignatures and habitable environment signatures can be grouped into ten broad categories. (10)
WHOOSH
We could look for biomolecules...
...minerals... textures...
ATMOSPHERIC GAS
ORGANIC MATTER
MINERALS
TEMPORAL VARIABILI
MACROSCOPIC PHYSICAL STRUCTURES
CHEMISTRY
TECHNOSI
...there are many options.
MICROSCOPIC TEXTURES AND STRUCTURES
STABLE ISOTOPE PATTERNS
SURFACE REFLECTANCE FEATURE VARIABILITY
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)


When the space age began, there were big hopes for finding life on planets in the Solar System.
We quickly found out that it wouldn't be so easy.
Well. Viking was right. Just rocks
Yay rocks!
Mars Pathfinder (NASA)*
The search for life beyond Earth relies on data from probes in our solar system, or astronomical observations.
Nyet. No Plants.
NASA hasn't sent a dedicated life detection instrument to space since Viking.*
Hey, there is some sort of liquid on Titan! Craaazzzy!
Venera (USSR)**
Don't see any life... but what is under Europa's icy shell?
Cassini-Huygens***
Galileo (NASA)***
Hey, Pluto has mountains!
Can anyone still hear me?
Voyager (NASA)***
New Horizons (NASA)***
So far, there isn't macroscopic life – or life we can see with the naked eye – on the surfaces of worlds in our system.
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.
*See Issue 2
**See Issue 3
***See Issue 4

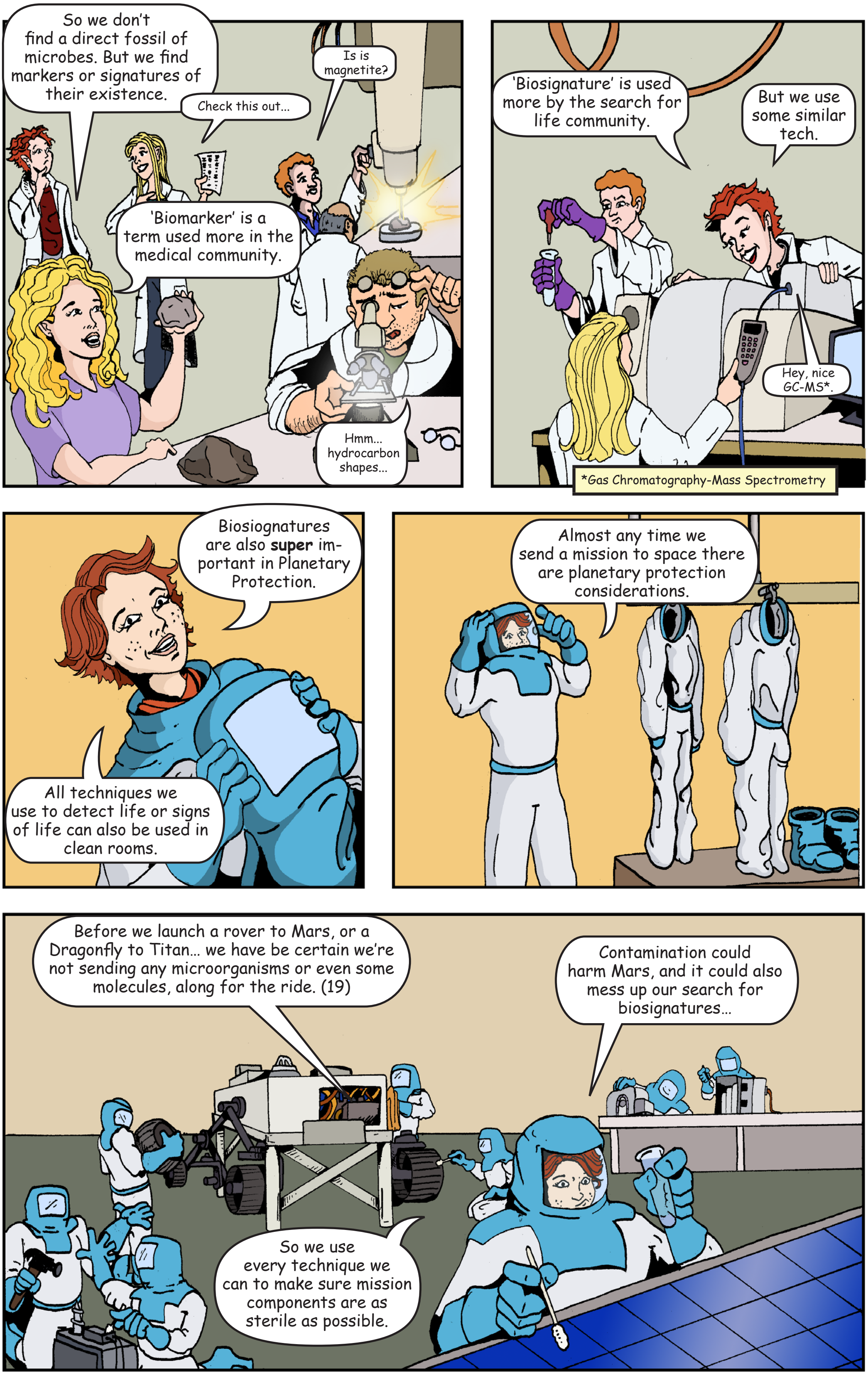

ALH84001 is a fragment from a martian meteorite that was found in the Allan Hills of Antarctica in 1984.
Are those microfossils in this meteorite? (13)
David S. McKay (1936-2013) (NASA Johnson Space Center)
Scientists may have found signs of ancient life on Mars!
Wait! We need more evidence! (14)
Andrew Steele (Carnegie Institute)
The micro-scopic 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, atmo-spheric 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...
(16)
For a time, we focused on the idea, 'follow the water'.

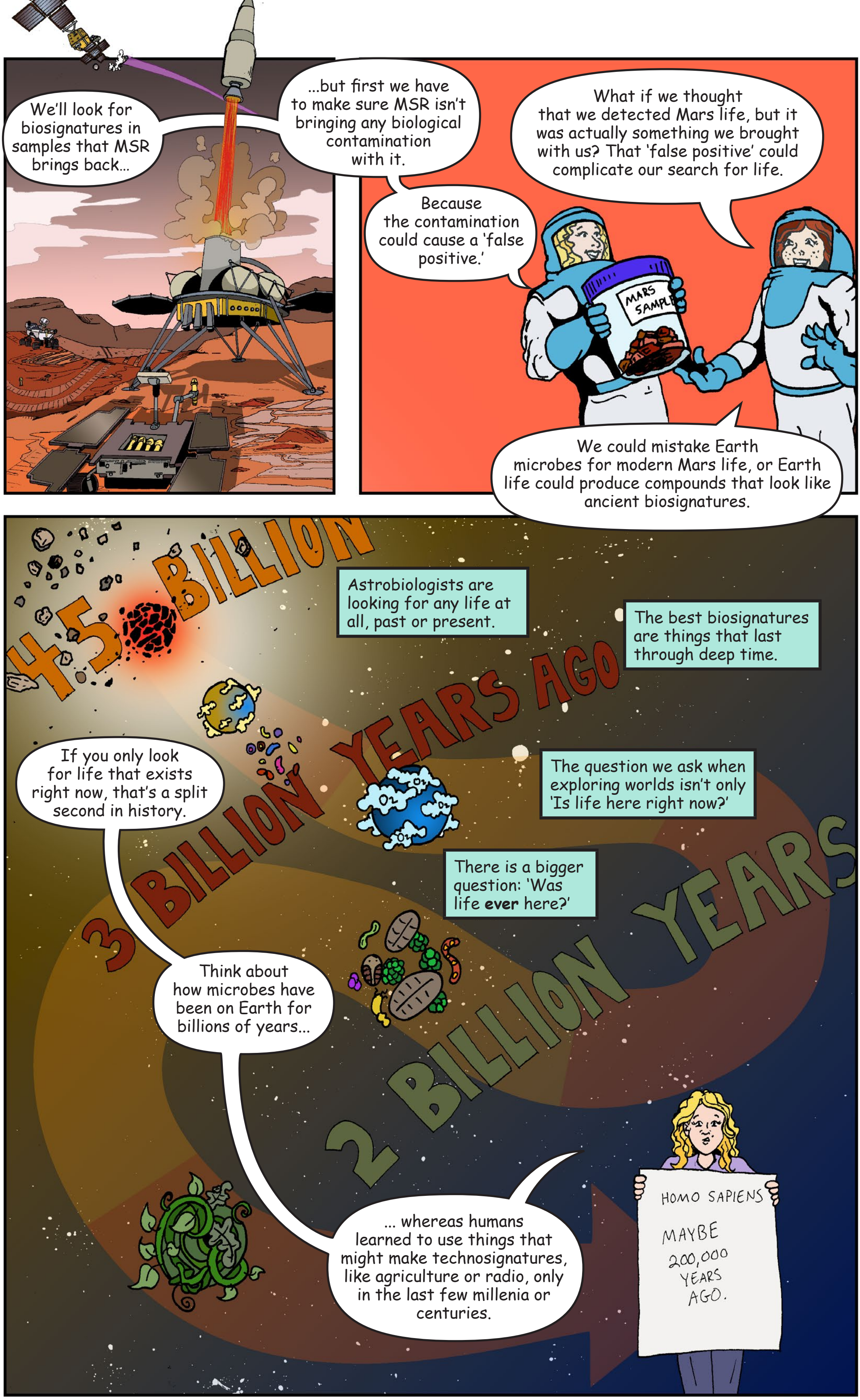

There totally used to be a hydrothermal vent here...
Opportunity Mars Exploration Rover (NASA)
Hey, I think there could've been fresh, flowing water here.
And it seems kind of gassy over there...
Curiosity Rover, Mars Science Laboratory (NASA)
Missions didn't only look for water on Mars...
... they looked EVERY-WHERE! And they found it.
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.**
Hubble Space Telescope
Deep Impact/EPOXI (NASA)
And they look back at Earth, both from space and in geological time, as an example of a watery world.**
Habitability assessment has helped us narrow down where to look...
...and now we're getting ready to specifically look for life again.
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.
MASS SPEC
CAMERAS IR
SMASHY TOOLS
PSTAR
MATISSE
ORBITER INSTRUMENTS
That's why we're so excited about the next step...
DRILLS
ROVER MENTS
ASTEP
PICASSO
*See Issue 4
**See Issue 6

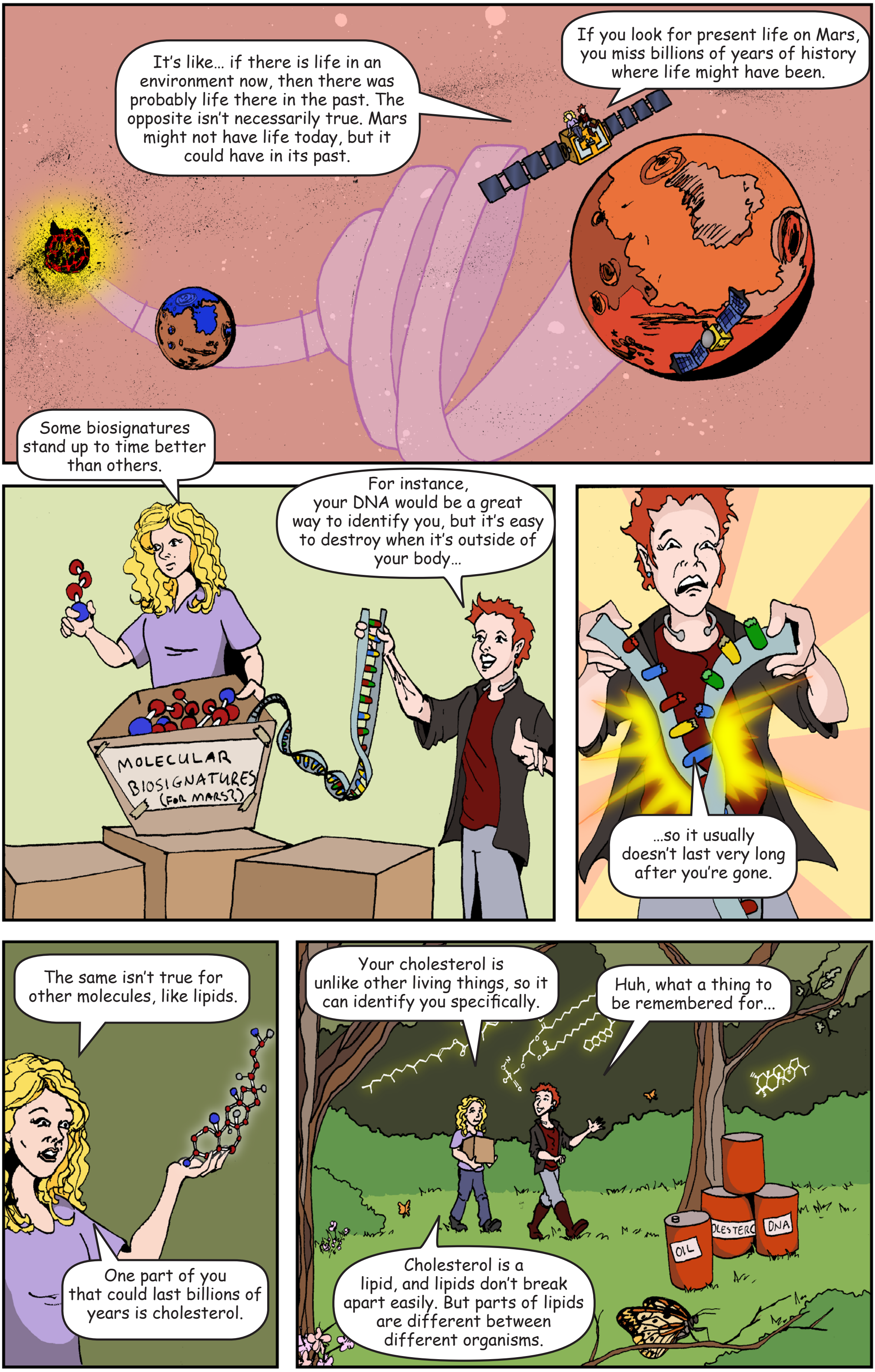

Right now, the Mars 2020 Perseverance rover is collecting samples that will be brought back to Earth for Mars Sample Return.*
*MSR, See Issue #2
In labs on Earth, scientists will then look at the samples using powerful instruments that cannot be flown on space missions.
And many different scientists 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.



Life as we know it uses water and carbon chemistry.
This chemistry produces things that we can identify. (17)
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.'
DR. G PhD
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.'
AHHHHH-THomethimeth, we think of cHhemical biomarthers athh mowecuwar fothh-hilth* -AHHH
DR. G PhD
*"Molecular fossils." Translated from tongue depressor English.
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.

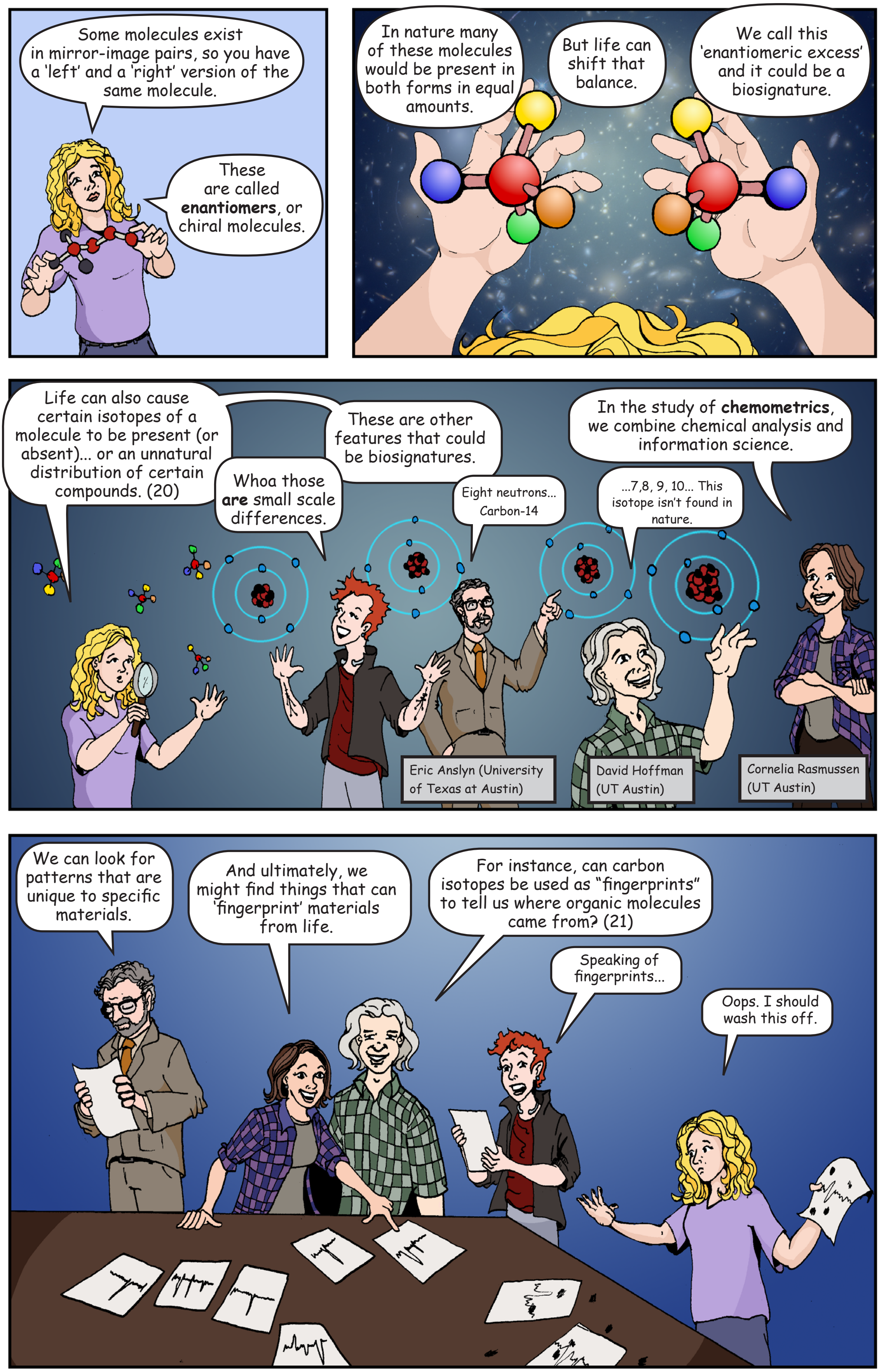

So we don't find a direct fossil of microbes. But we find markers or signatures of their existence.
Check this out...
Is is magnetite?
'Biomarker' is a term used more in the medical community.
Hmm... hydrocarbon shapes...
'Biosignature' is used more by the search for life community.
But we use some similar tech.
Hey, nice GC-MS*.
*Gas Chromatography-Mass Spectrometry
Biosiognatures are also **super** important in Planetary Protection.
All techniques we use to detect life or signs of life can also be used in clean rooms.
Almost any time we send a mission to space there are planetary protection considerations.
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.

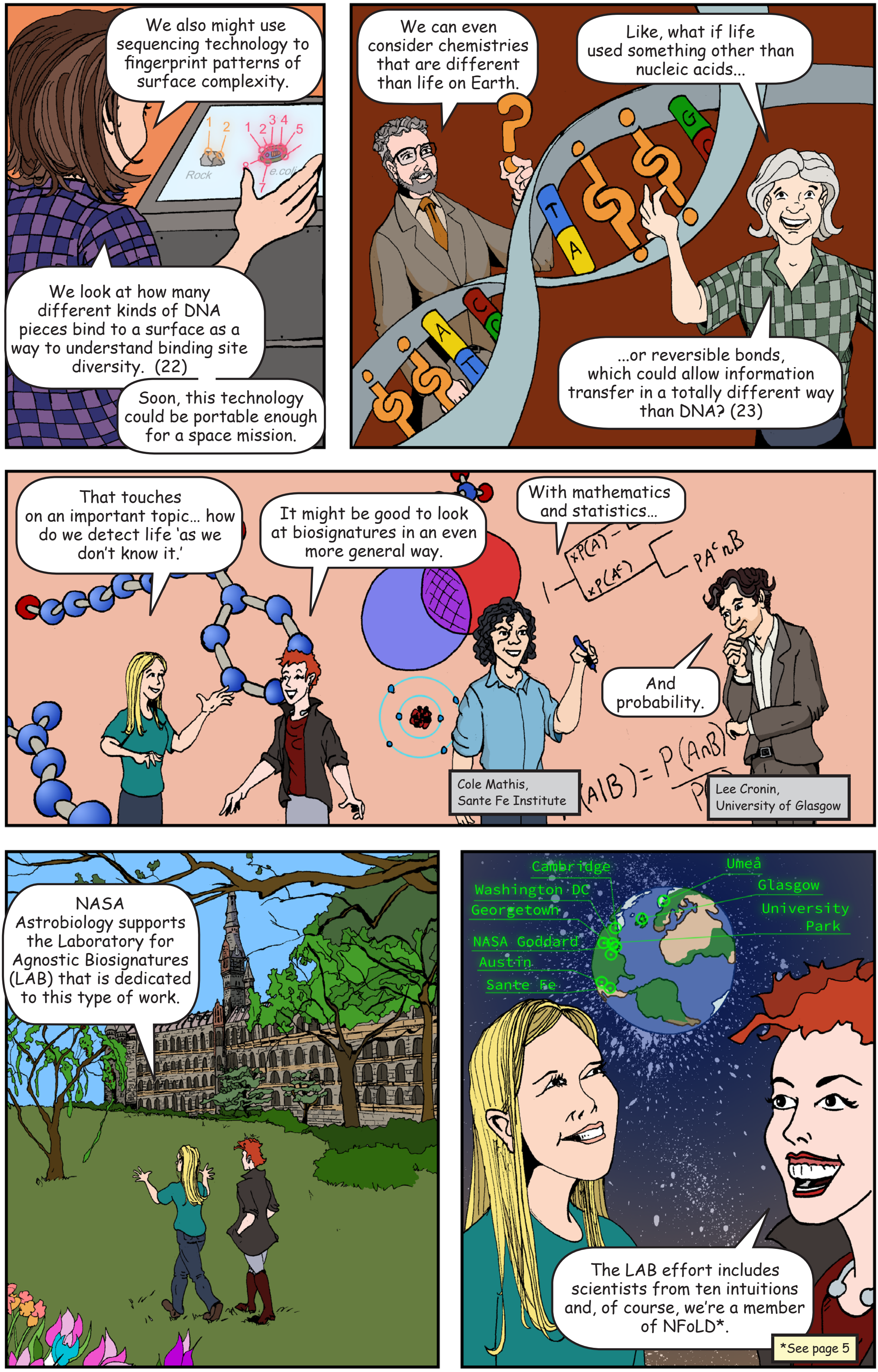

We'll look for biosignatures in samples that MSR brings back...
...but first we have to make sure MSR isn't bringing any biological contamination with it.
Because the contamination could cause a 'false positive.'
What if we thought that we detected Mars life, but it was actually something we brought with us? That 'false positive' could complicate our search for life.
MARS SAMPLE
We could mistake Earth microbes for modern Mars life, or Earth life could produce compounds that look like ancient biosignatures.
4.5 BILLION YEARS AGO
Astrobiologists are looking for any life at all, past or present.
The best biosignatures are things that last through deep time.
3 BILLION YEARS
2 BILLION YEARS
If you only look for life that exists right now, that's a split second in history.
The question we ask when exploring worlds isn't only 'Is life here right now?'
There is a bigger question: 'Was life **ever** here?'
Think about how microbes have been on Earth for billions of years...
... whereas humans learned to use things that might make technosignatures, like agriculture or radio, only in the last few millenia or centuries.
HOMO SAPIENS
MAYBE 200,000 YEARS AGO.



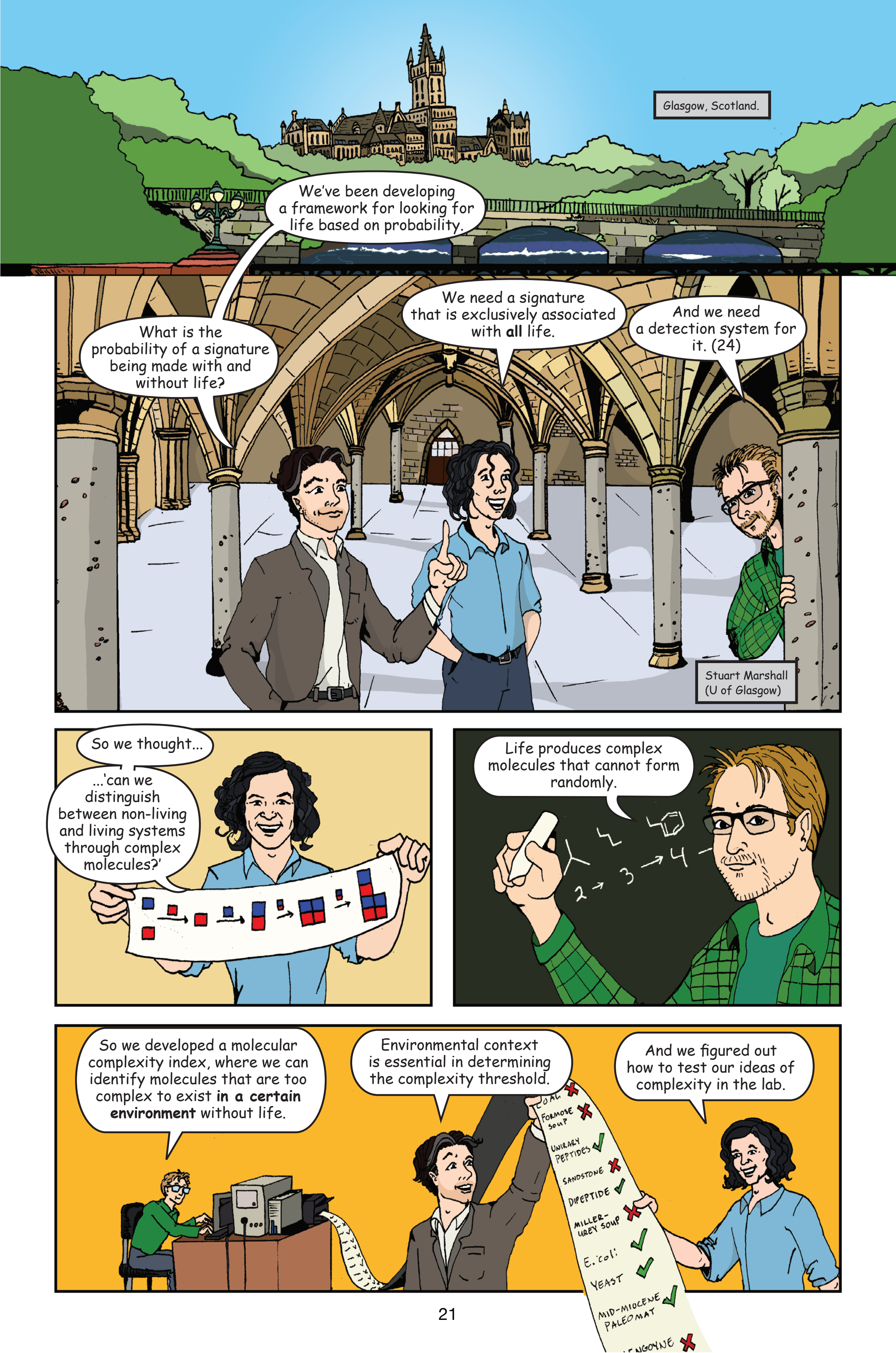
It's like… if there is life in an environment now, then there was probably life there in the past. The opposite isn't necessarily true. Mars might not have life today, but it could have in its past.
If you look for present life on Mars, you miss billions of years of history where life might have been.
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…
MOLECULAR BIOSIGNATURES (FOR MARS?)
…so it usually doesn't last very long after you're gone.
The same isn't true for other molecules, like lipids.
One part of you that could last billions of years is cholesterol.
Your cholesterol is unlike other living things, so it can identify you specifically.
Huh, what a thing to be remembered for…
Cholesterol is a lipid, and lipids don't break apart easily. But parts of lipids are different between different organisms.
OIL
DNA


Oops!
BANG!
DNA
OIL
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.
OIL
DNA
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.

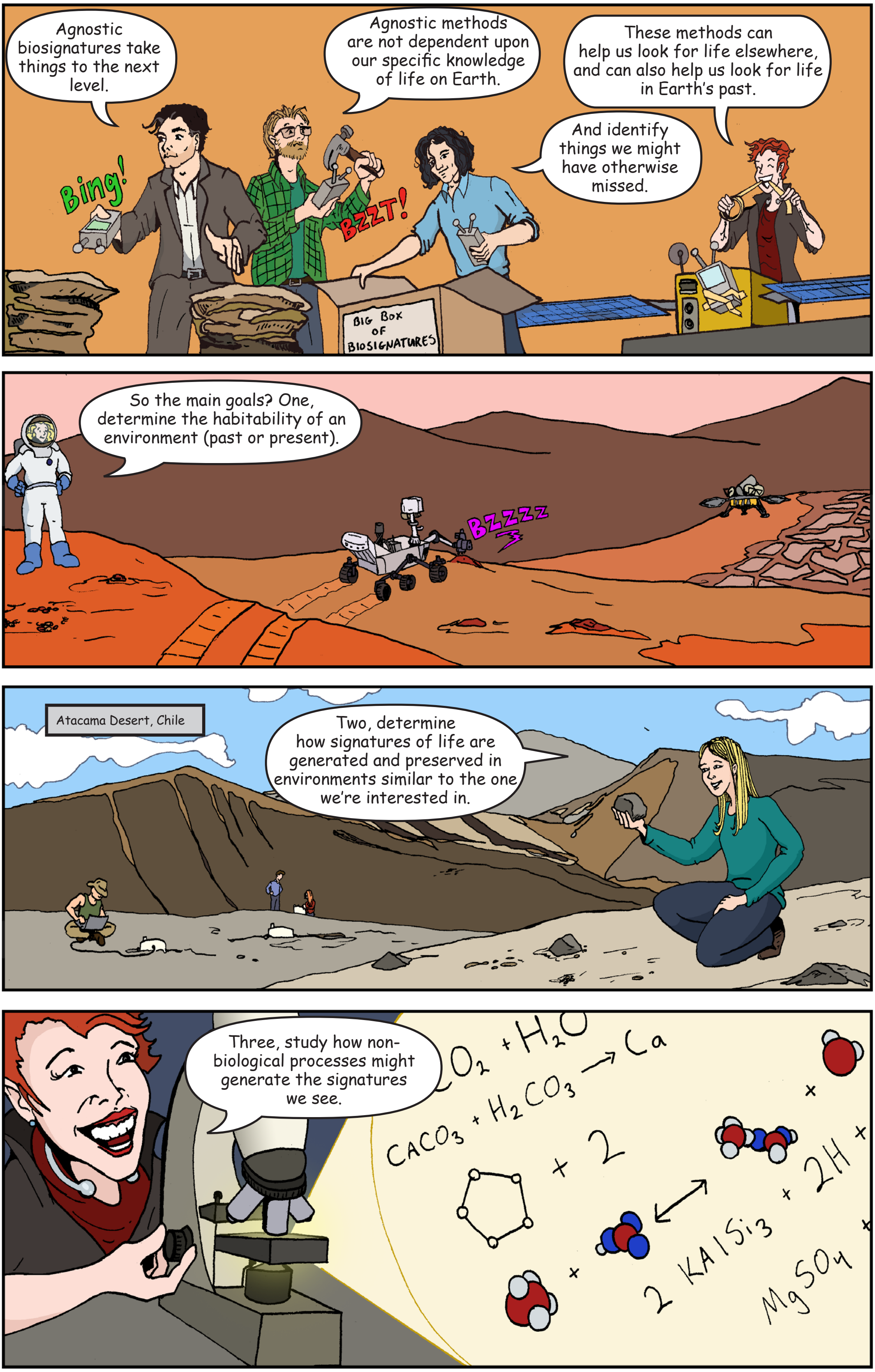

Some molecules exist in mirror-image pairs, so you have a 'left' and a 'right' version of the same molecule.
These are called **enantiomers**, or chiral molecules.
In nature many of these molecules would be present in both forms in equal amounts.
But life can shift that balance.
We call this 'enantiomeric excess' and it could be a biosignature.
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.
Whoa those **are** small scale differences.
Eight neutrons... Carbon-14
...7,8, 9, 10... This isotope isn't found in nature.
In the study of **chemometrics**, we combine chemical analysis and information science.
Eric Anslyn (University of Texas at Austin)
David Hoffman (UT Austin)
Cornelia Rasmussen (UT Austin)
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.

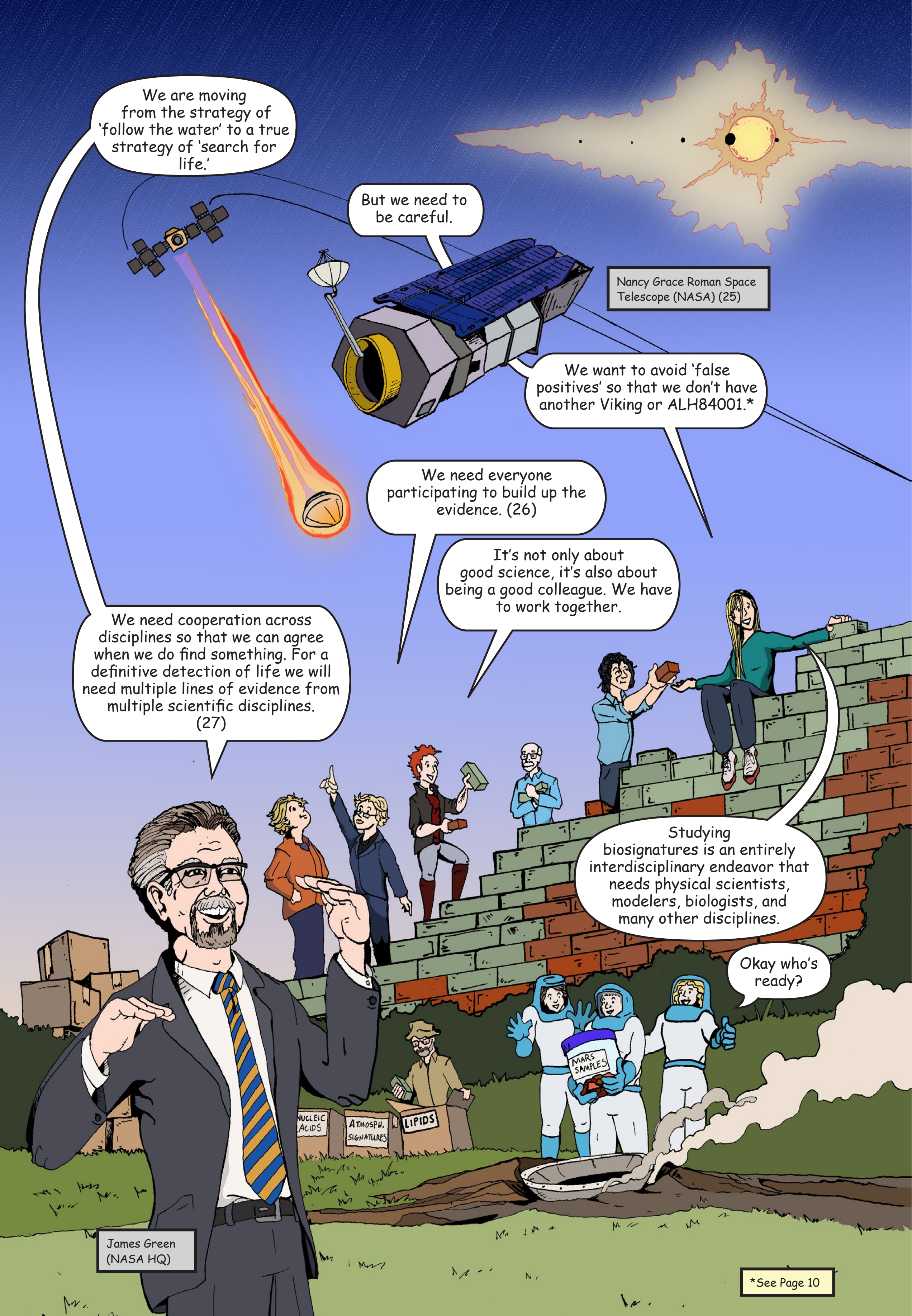

We also might use sequencing technology to fingerprint patterns of surface complexity.
Rock
We look at how many different kinds of DNA pieces bind to a surface as a way to understand binding site diversity. (22)
Soon, this technology could be portable enough for a space mission.
We can even consider 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)
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.
Cole Mathis, Sante Fe Institute
Lee Cronin, University of Glasgow
NASA Astrobiology supports the Laboratory for Agnostic Biosignatures (LAB) that is dedicated to this type of work.
Cambridge
Washington DC
Georgetown
NASA Goddard
Austin
Sante Fe
Umeå
Glasgow
University Park
The LAB effort includes scientists from ten intuitions and, of course, we're a member of NFoLD*.
*See page 5


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?'
BURP!
BURP!
BURP!
Organisms are in constant response to the environment.
We can look at things that might be expressions of life in an environment...
...like molecules...
...or macroscopic structures...
...like buildings or anything else that looks like it took **energy** to make.
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.
Life is that extra 'push' of energy needed in a specific environment to make a specific expression.
CLICK!



Glasgow, Scotland.
We've been developing a framework for looking for life based on probability.
What is the probability of a signature being made with and without life?
We need a signature that is exclusively associated with **all** life.
And we need a detection system for it. (24)
Stuart Marshall (U of Glasgow)
So we thought...
...'can we distinguish between non-living and living systems through complex molecules?'
Life produces complex molecules that cannot form randomly.
2 → 3 → 4
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.
COAL
FORMOSE SOUP
UNIRARY PEPTIDES
SANDSTONE
DIPEPTIDE
MILLER-UREY SOUP
E. coli
YEAST
MID-MIOCENE PALEOMAT
And we figured out how to test our ideas of complexity in the lab.


Agnostic biosignatures take things to the next level.
Bing!
Agnostic methods are not dependent upon our specific knowledge of life on Earth.
BZZT!
BIG BOX OF BIOSIGNATURES
And identify things we might have otherwise missed.
These methods can help us look for life elsewhere, and can also help us look for life in Earth's past.
So the main goals? One, determine the habitability of an environment (past or present).
BZZZZ
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.
CO2 + H2O
CACO3 + H2CO3 → Ca
+ 2
2 KAlSi3
+ 2H +
MgSO4


We are moving from the strategy of 'follow the water' to a true strategy of 'search for life.'
But we need to be careful.
Nancy Grace Roman Space Telescope (NASA) (25)
We want to avoid 'false positives' so that we don't have another Viking or ALH84001.*
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.
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)
Studying biosignatures is an entirely interdisciplinary endeavor that needs physical scientists, modelers, biologists, and many other disciplines.
Okay who's ready?
MARS SAMPLES
NUCLEIC ACIDS
ATMOSPH. SIGNATURES
LIPIDS
James Green (NASA HQ)
*See Page 10

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