National Aeronautics and Space Administration

NASA

Issue #6

2nd EDITION

ASTROBIOLOGY

The Story of our Search for Life in the Universe

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. Beginning shortly after the establishment of NASA, this field is relatively young. However, as you will see, the questions that astrobiologists are trying to answer are as old as humankind.

Concept & Story

Mary Voytek
Linda Billings
Aaron L. Gronstal

Artwork

Aaron L. Gronstal

Script

Aaron L. Gronstal
Jordan Rizzieri

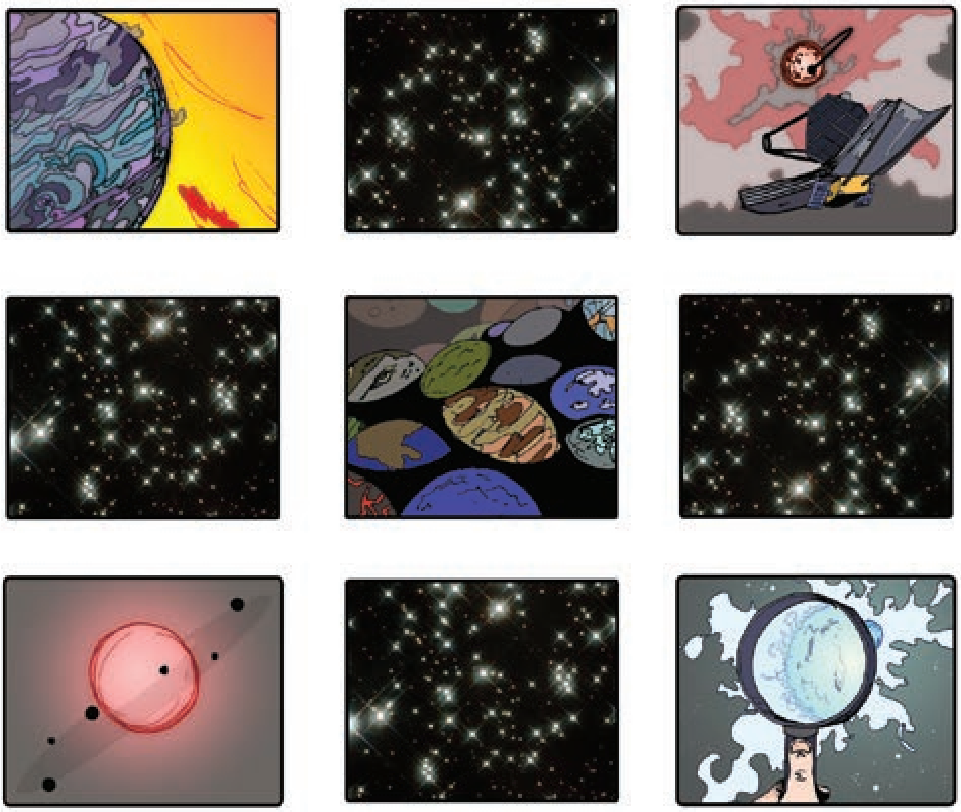
Editor

Linda Billings

Layout

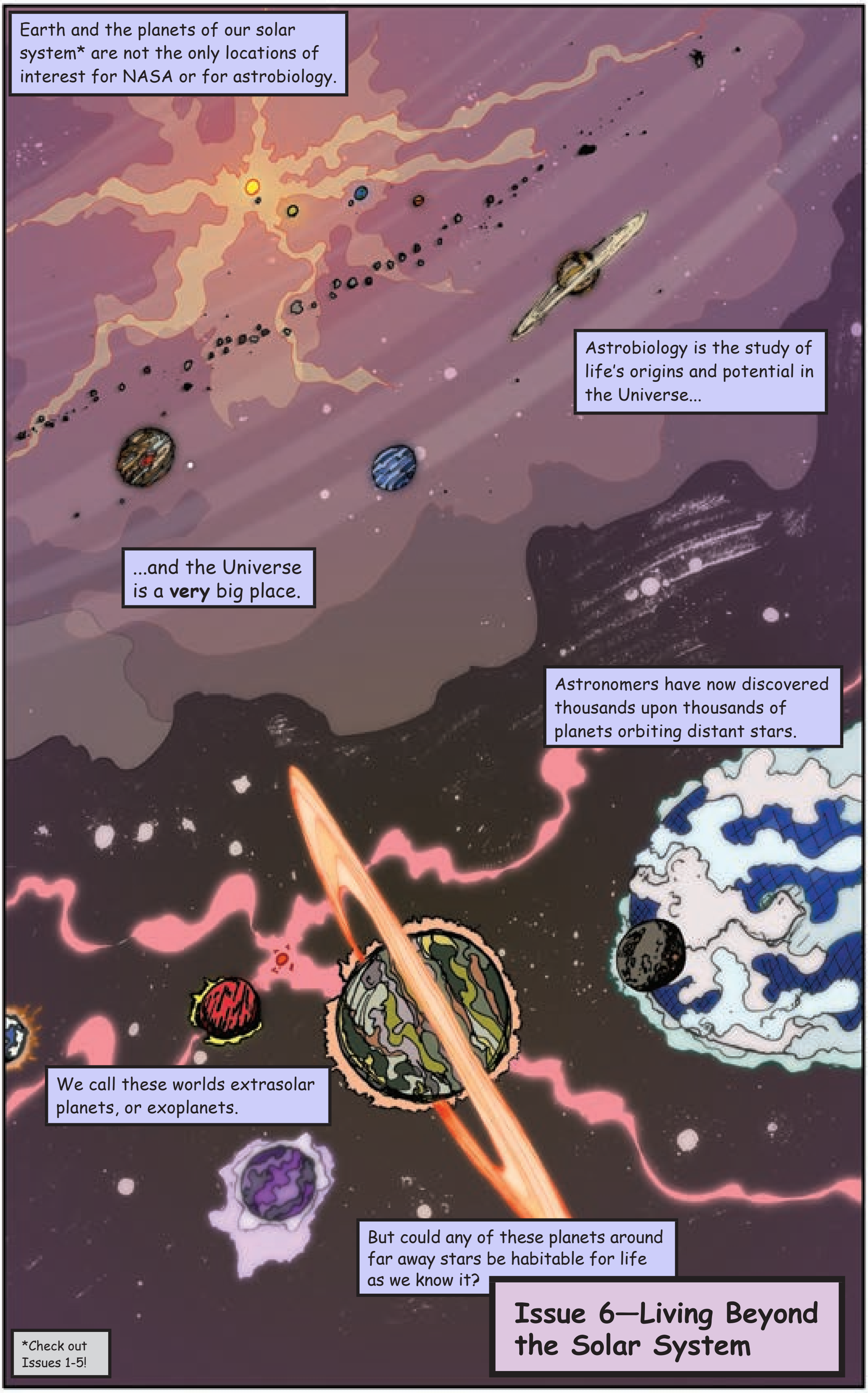
Aaron L. Gronstal
Jenny Mottar

Issue #6—Living Beyond the Solar System

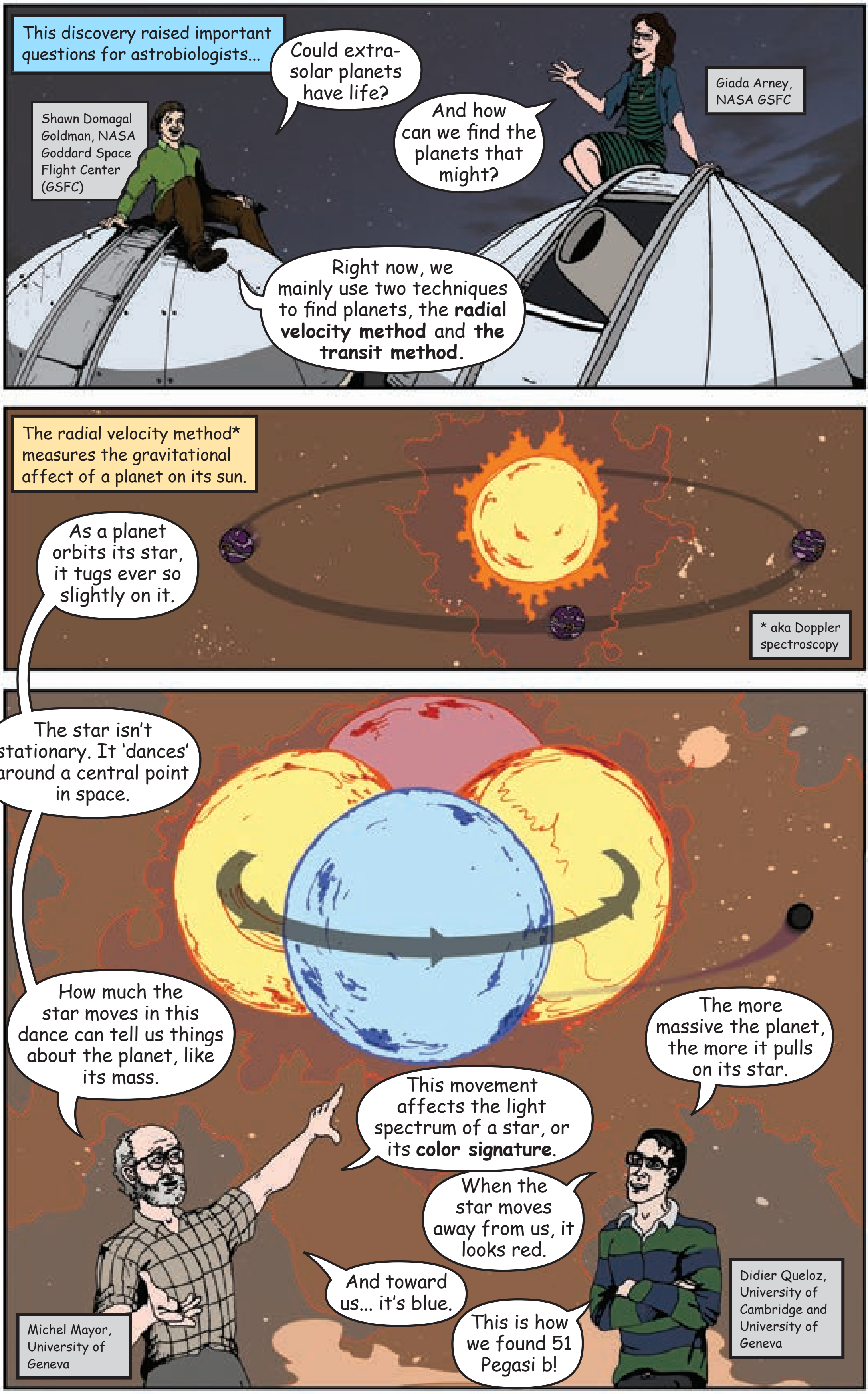


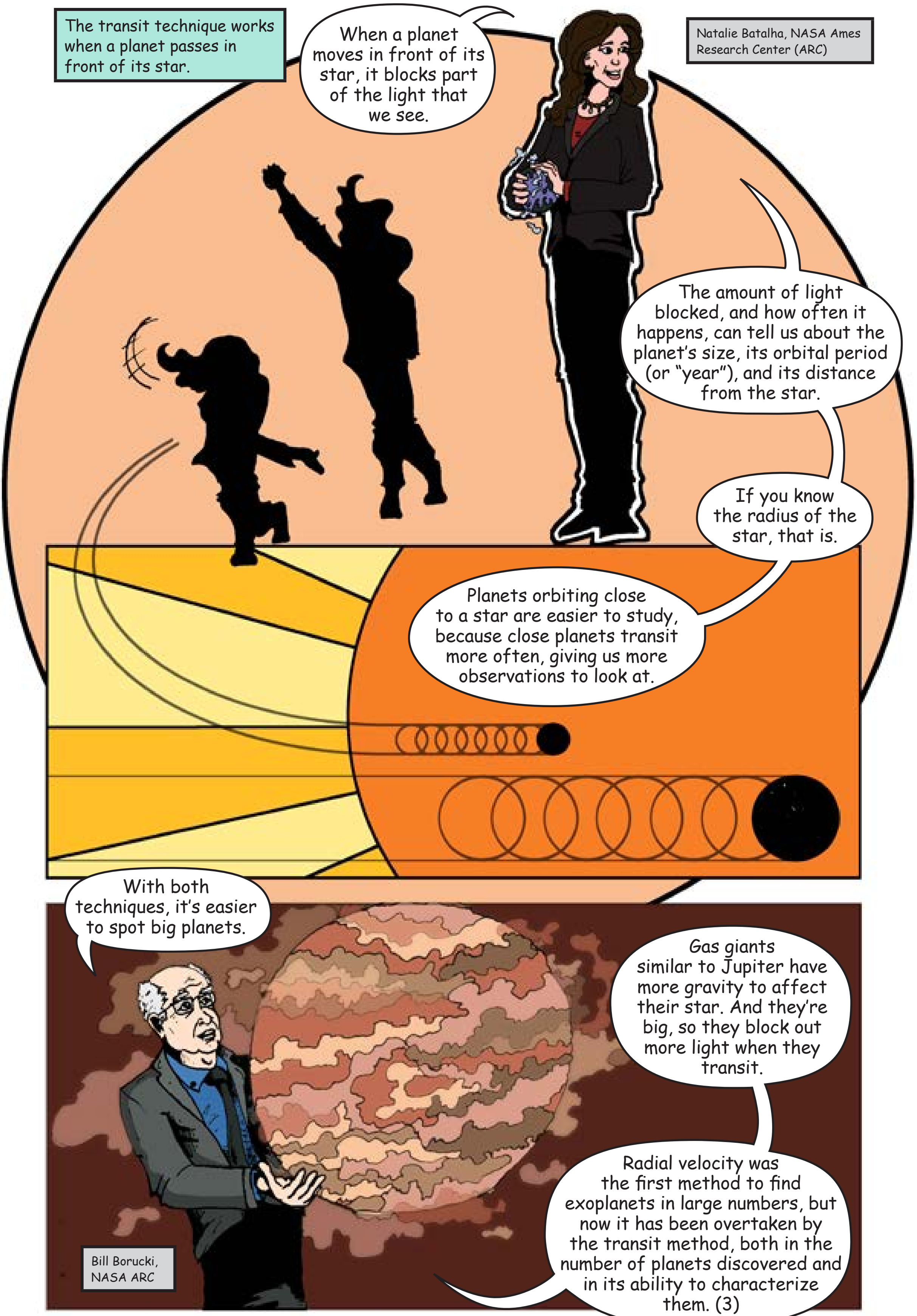
The year 2010 marked the 50th anniversary of NASA's Exobiology Program, established in 1960 and expanded into a broader Astrobiology Program in the 1990s. We are telling the story of how this field developed and how the search for life elsewhere became a key component of NASA's science strategy for exploring space. This issue is the sixth in 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.

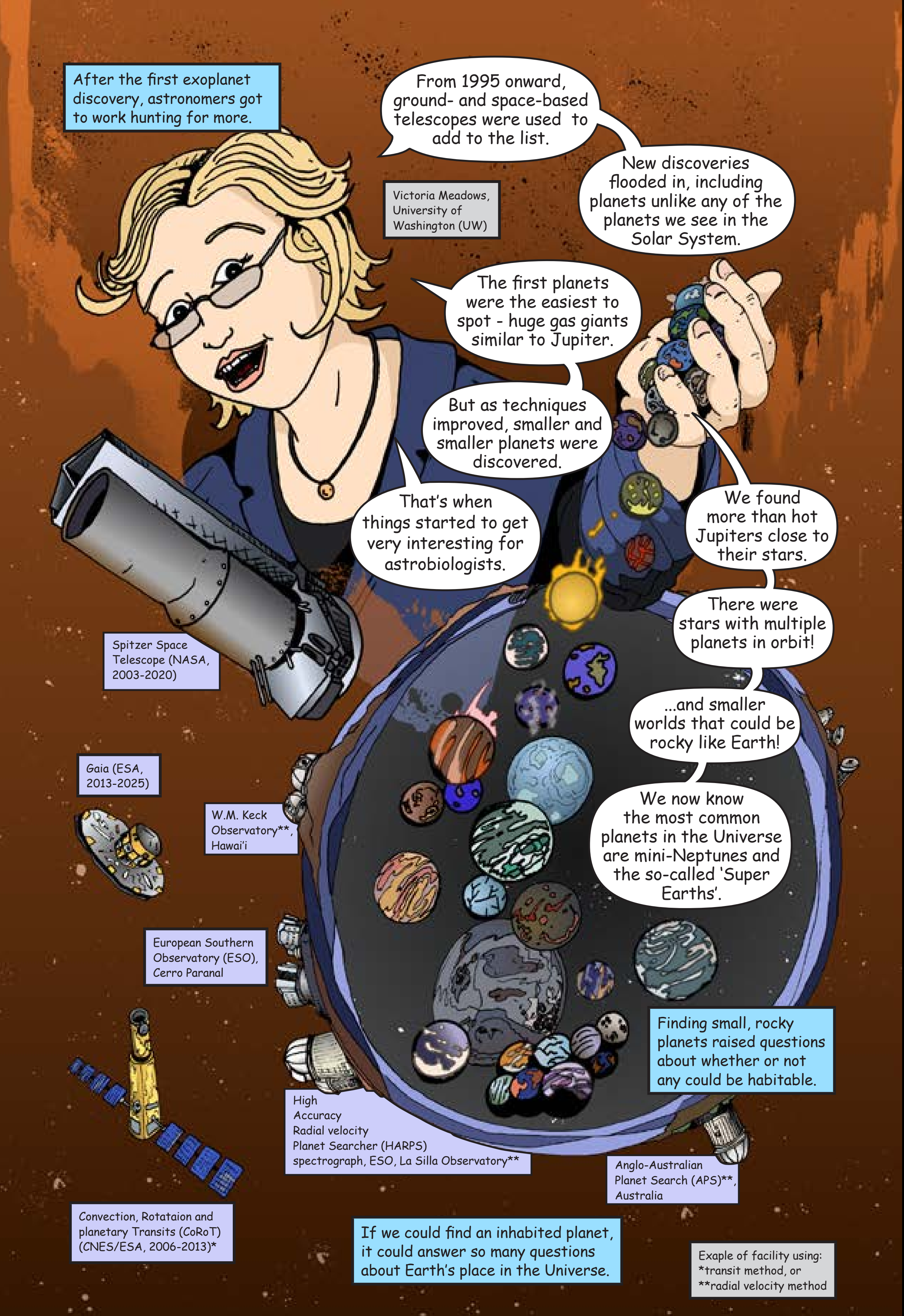
-Linda Billings, Editor

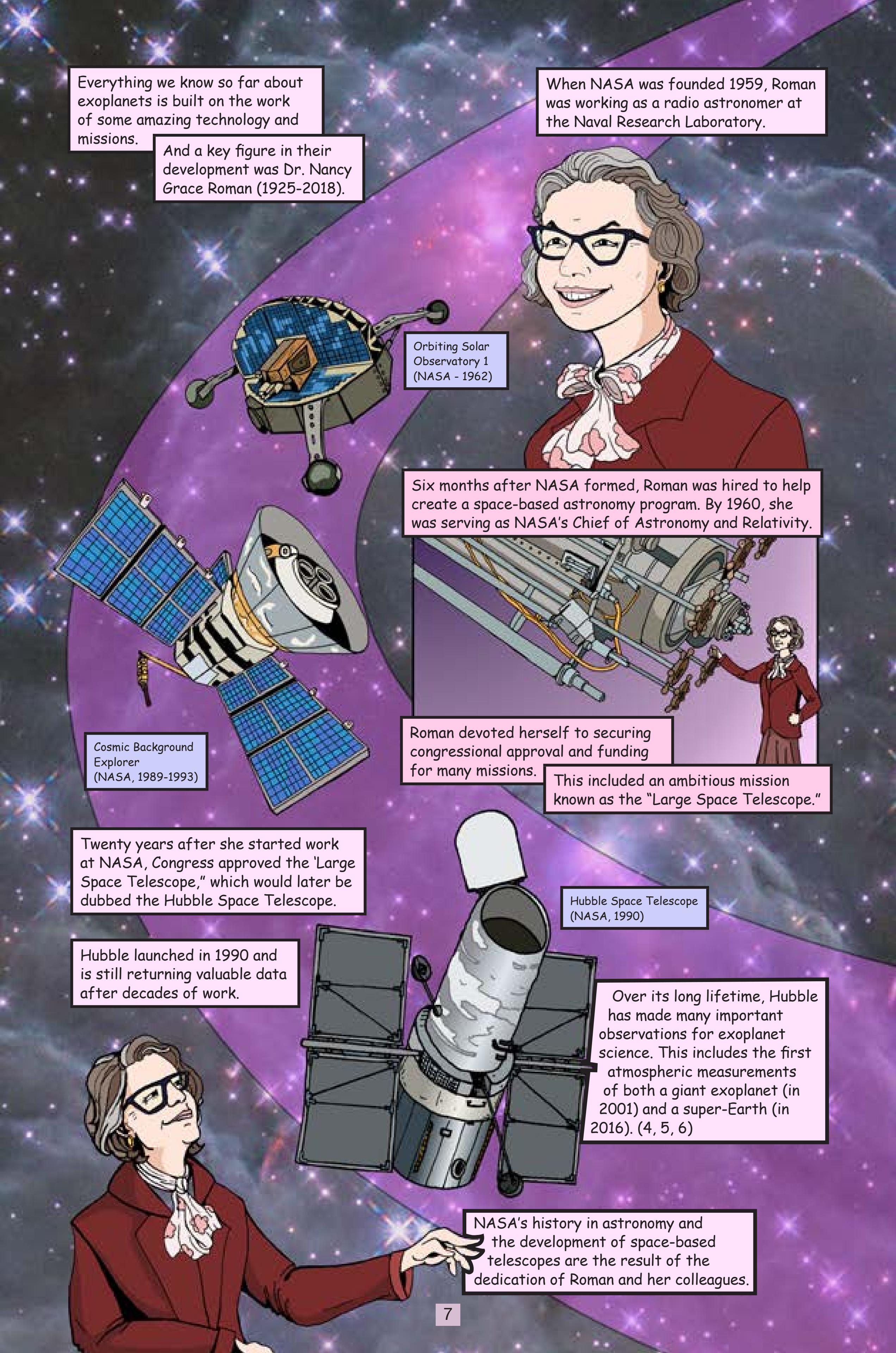

Earth and the planets of our solar system* are not the only locations of interest for NASA or for astrobiology.
Astrobiology is the study of life's origins and potential in the Universe...
...and the Universe is a **very** big place.
Astronomers have now discovered thousands upon thousands of planets orbiting distant stars.
We call these worlds extrasolar planets, or exoplanets.
But could any of these planets around far away stars be habitable for life as we know it?
Issue 6—Living Beyond the Solar System
*Check out Issues 1-5!

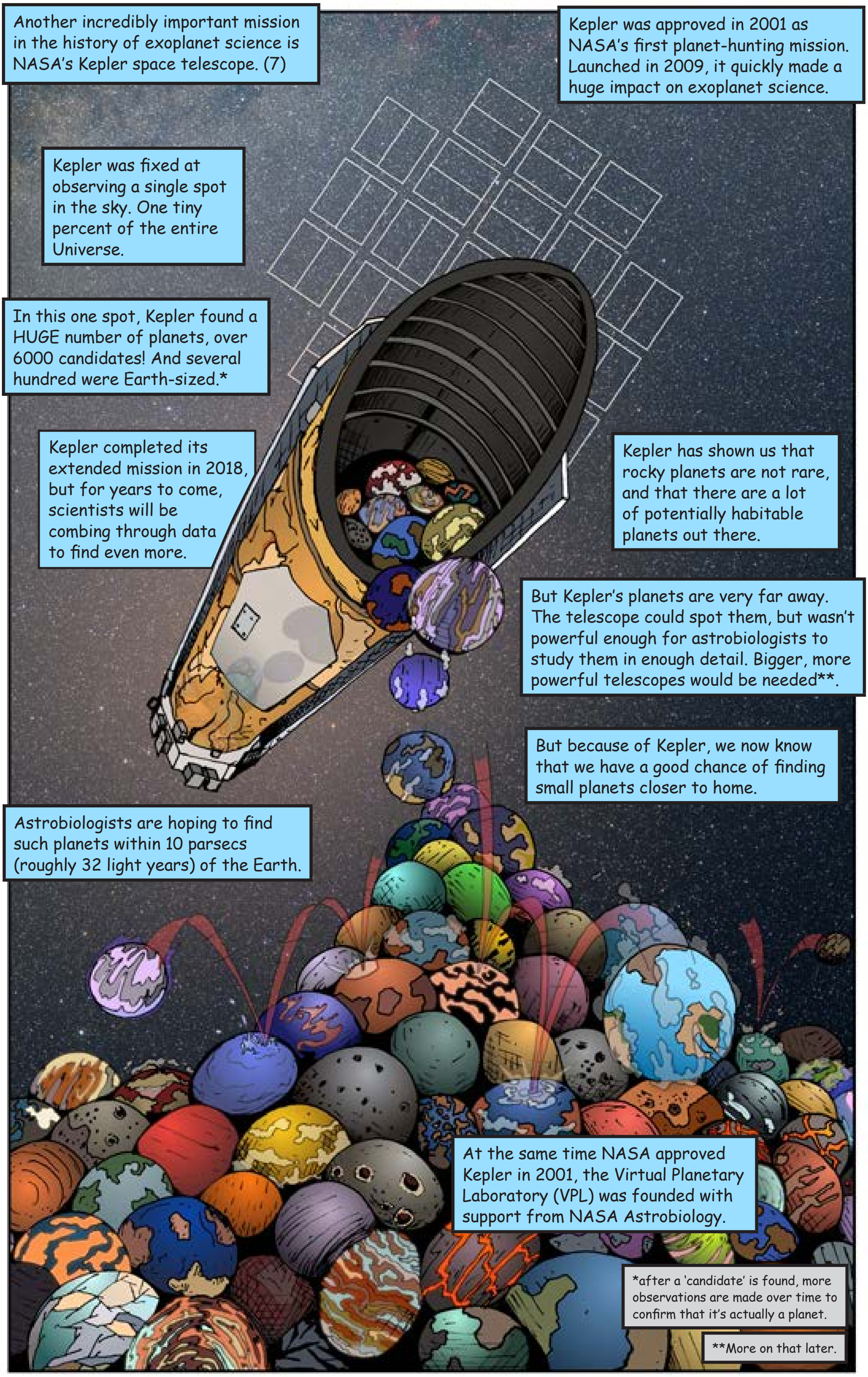

Scientists and philosophers have debated the potential for extrasolar planets for centuries (and long before NASA existed).*
I believe in a 'plurality of worlds.'
There are countless Earths rotating around their suns in exactly the same way as the planets of our system.
*see Issue #1
Giordano Bruno, (1548-1600) (1)
We see only the suns because they are large and luminous...
...but their planets remain invisible to us because they are smaller and non-luminous.
As time went on, technology improved and changed our view of the Universe.
Edwin Hubble (1889-1953), at work in the 1920s.
Wait, those clouds of light are galaxies!
Whoa...
...that is a **lot** of stars.
In 1995, astronomers finally found an extrasolar planet orbiting a distant star.
Mon dieu...
A giant planet rapidly orbits the star 51 Pegasi! (2)
Haute-Provence Observatory, 1995.
A gas giant planet like 51 Pegasi b isn't habitable... but it proved that exoplanets did indeed exist.

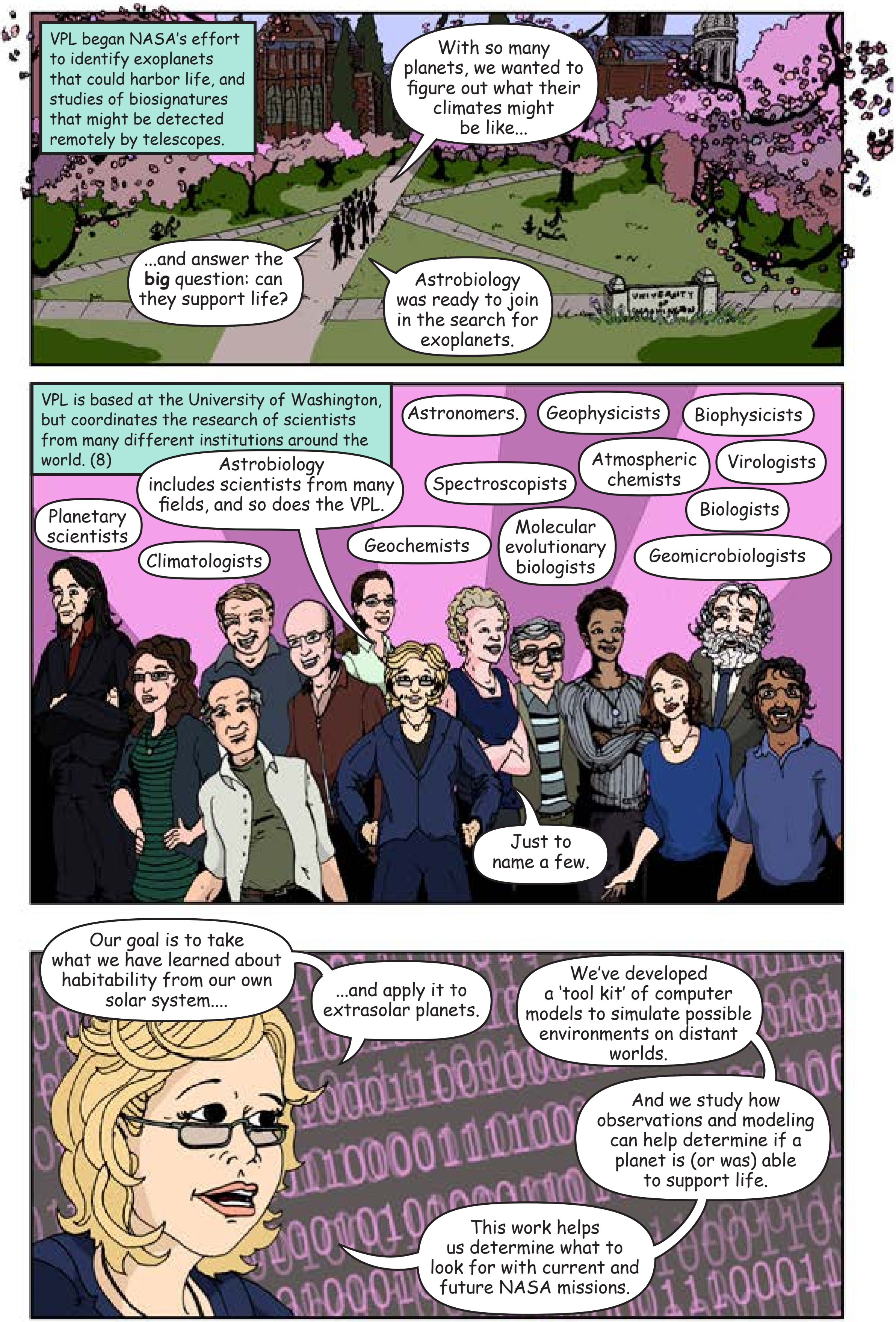

This discovery raised important questions for astrobiologists...
Shawn Domagal Goldman, NASA Goddard Space Flight Center (GSFC)
Could extra-solar planets have life?
Giada Arney, NASA GSFC
And how can we find the planets that might?
Right now, we mainly use two techniques to find planets, the **radial velocity method** and **the transit method**.
The radial velocity method* measures the gravitational affect of a planet on its sun.
As a planet orbits its star, it tugs ever so slightly on it.
* aka Doppler spectroscopy
The star isn't stationary. It 'dances' around a central point in space.
How much the star moves in this dance can tell us things about the planet, like its mass.
The more massive the planet, the more it pulls on its star.
This movement affects the light spectrum of a star, or its **color signature**.
When the star moves away from us, it looks red.
And toward us... it's blue.
This is how we found 51 Pegasi b!
Michel Mayor, University of Geneva
Didier Queloz, University of Cambridge and University of Geneva


The transit technique works when a planet passes in front of its star.
When a planet moves in front of its star, it blocks part of the light that we see.
Natalie Batalha, NASA Ames Research Center (ARC)
The amount of light blocked, and how often it happens, can tell us about the planet's size, its orbital period (or "year"), and its distance from the star.
If you know the radius of the star, that is.
Planets orbiting close to a star are easier to study, because close planets transit more often, giving us more observations to look at.
With both techniques, it's easier to spot big planets.
Gas giants similar to Jupiter have more gravity to affect their star. And they're big, so they block out more light when they transit.
Radial velocity was the first method to find exoplanets in large numbers, but now it has been overtaken by the transit method, both in the number of planets discovered and in its ability to characterize them. (3)
Bill Borucki, NASA ARC

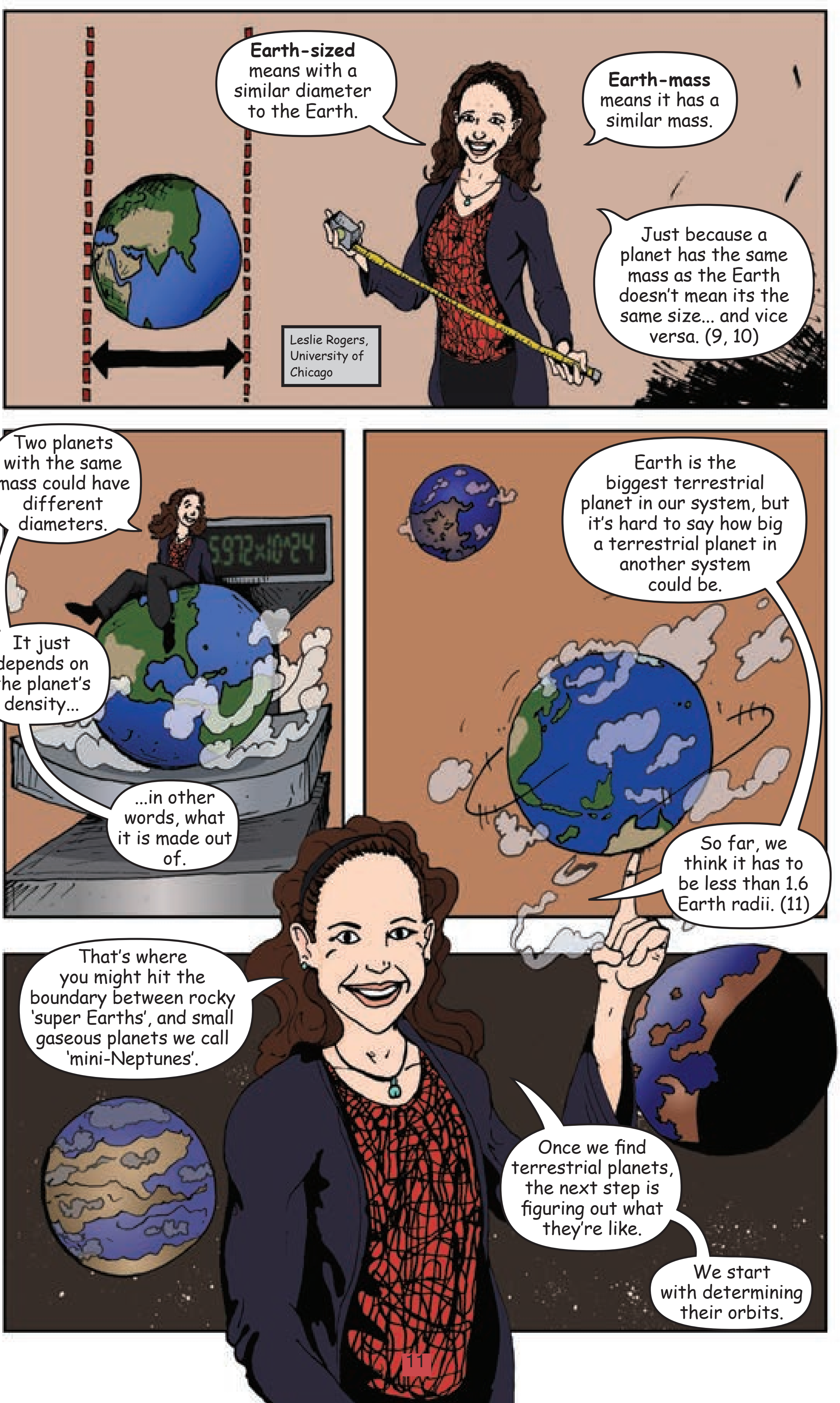

After the first exoplanet discovery, astronomers got to work hunting for more.
From 1995 onward, ground- and space-based telescopes were used to add to the list.
Victoria Meadows, University of Washington (UW)
New discoveries flooded in, including planets unlike any of the planets we see in the Solar System.
The first planets were the easiest to spot - huge gas giants similar to Jupiter.
But as techniques improved, smaller and smaller planets were discovered.
That's when things started to get very interesting for astrobiologists.
We found more than hot Jupiters close to their stars.
There were stars with multiple planets in orbit!
...and smaller worlds that could be rocky like Earth!
We now know the most common planets in the Universe are mini-Neptunes and the so-called 'Super Earths'.
Spitzer Space Telescope (NASA, 2003-2020)
Gaia (ESA, 2013-2025)
W.M. Keck Observatory**, Hawai'i
European Southern Observatory (ESO), Cerro Paranal
Finding small, rocky planets raised questions about whether or not any could be habitable.
High Accuracy Radial velocity Planet Searcher (HARPS) spectrograph, ESO, La Silla Observatory**
Anglo-Australian Planet Search (APS)**, Australia
Convection, Rotataion and planetary Transits (CoRoT) (CNES/ESA, 2006-2013)*
If we could find an inhabited planet, it could answer so many questions about Earth's place in the Universe.
Exaple of facility using:
*transit method, or
**radial velocity method


Everything we know so far about exoplanets is built on the work of some amazing technology and missions.
And a key figure in their development was Dr. Nancy Grace Roman (1925-2018).
When NASA was founded 1959, Roman was working as a radio astronomer at the Naval Research Laboratory.
Orbiting Solar Observatory 1 (NASA - 1962)
Six months after NASA formed, Roman was hired to help create a space-based astronomy program. By 1960, she was serving as NASA's Chief of Astronomy and Relativity.
Cosmic Background Explorer (NASA, 1989-1993)
Roman devoted herself to securing congressional approval and funding for many missions.
This included an ambitious mission known as the "Large Space Telescope."
Twenty years after she started work at NASA, Congress approved the 'Large Space Telescope," which would later be dubbed the Hubble Space Telescope.
Hubble Space Telescope (NASA, 1990)
Hubble launched in 1990 and is still returning valuable data after decades of work.
Over its long lifetime, Hubble has made many important observations for exoplanet science. This includes the first atmospheric measurements of both a giant exoplanet (in 2001) and a super-Earth (in 2016). (4, 5, 6)
NASA's history in astronomy and the development of space-based telescopes are the result of the dedication of Roman and her colleagues.

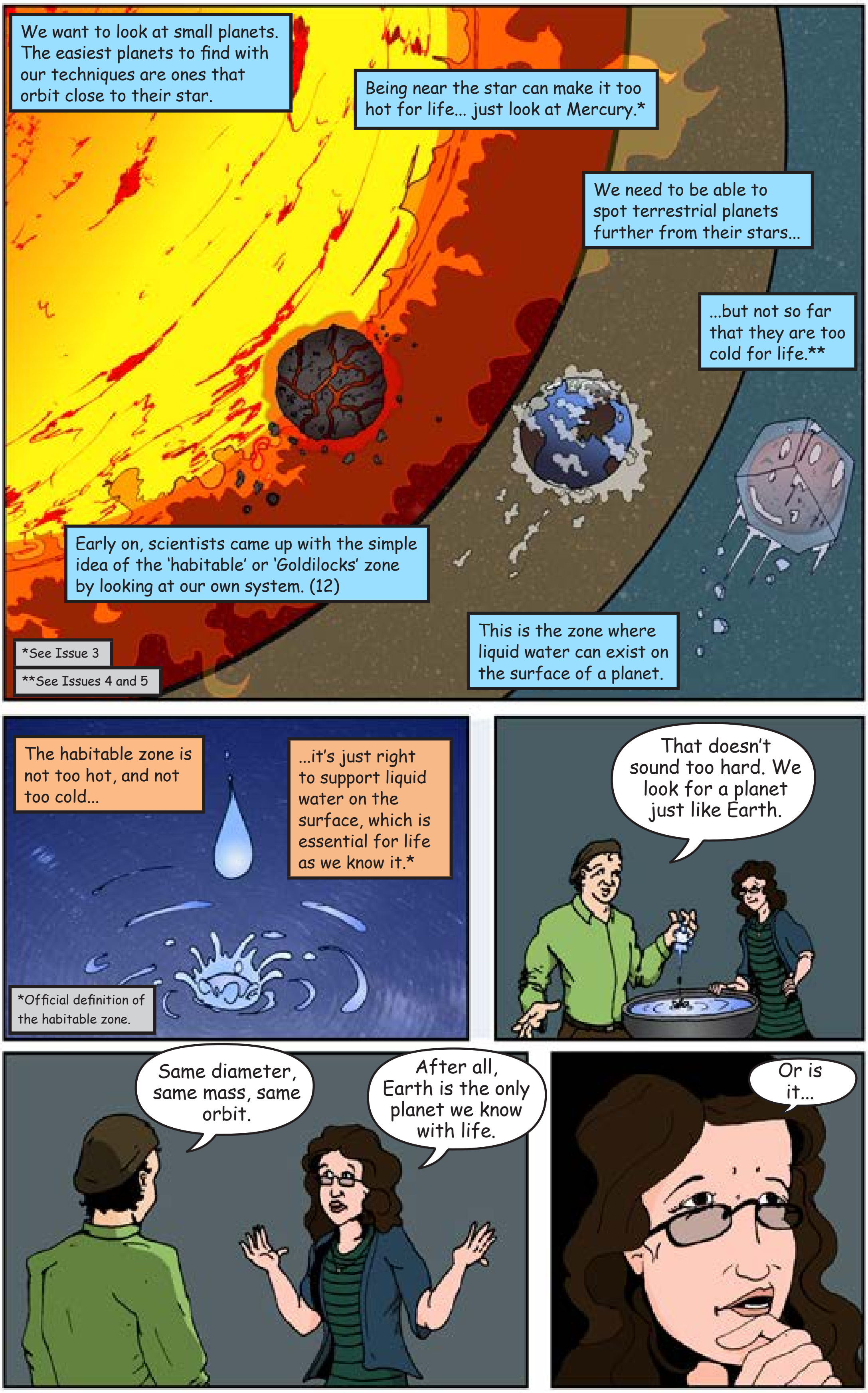

Another incredibly important mission in the history of exoplanet science is NASA's Kepler space telescope. (7)
Kepler was approved in 2001 as NASA's first planet-hunting mission. Launched in 2009, it quickly made a huge impact on exoplanet science.
Kepler was fixed at observing a single spot in the sky. One tiny percent of the entire Universe.
In this one spot, Kepler found a HUGE number of planets, over 6000 candidates! And several hundred were Earth-sized.*
Kepler completed its extended mission in 2018, but for years to come, scientists will be combing through data to find even more.
Kepler has shown us that rocky planets are not rare, and that there are a lot of potentially habitable planets out there.
But Kepler's planets are very far away. The telescope could spot them, but wasn't powerful enough for astrobiologists to study them in enough detail. Bigger, more powerful telescopes would be needed**.
But because of Kepler, we now know that we have a good chance of finding small planets closer to home.
Astrobiologists are hoping to find such planets within 10 parsecs (roughly 32 light years) of the Earth.
At the same time NASA approved Kepler in 2001, the Virtual Planetary Laboratory (VPL) was founded with support from NASA Astrobiology.
*after a 'candidate' is found, more observations are made over time to confirm that it's actually a planet.
**More on that later.

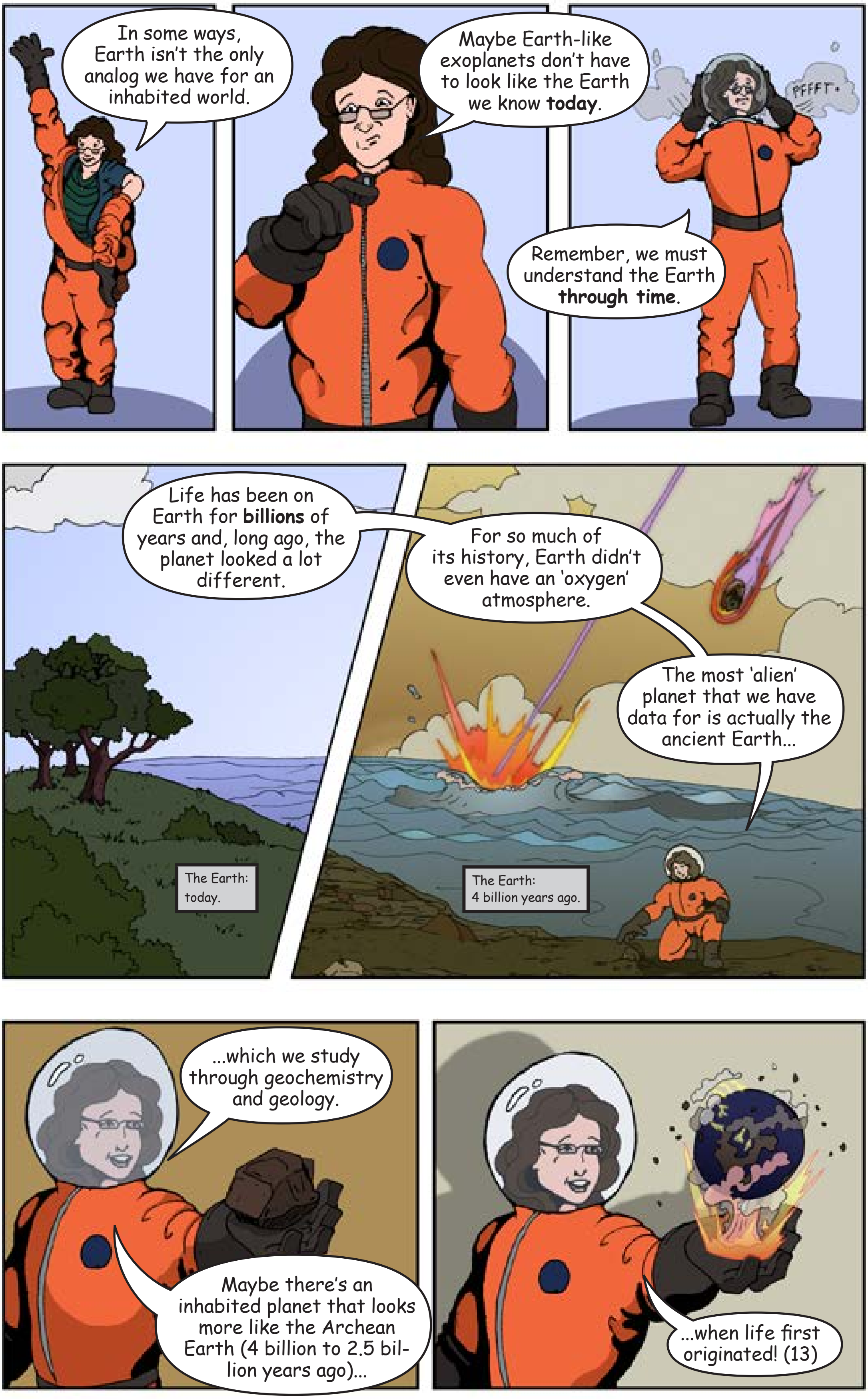

VPL began NASA's effort to identify exoplanets that could harbor life, and studies of biosignatures that might be detected remotely by telescopes.
With so many planets, we wanted to figure out what their climates might be like...
...and answer the **big** question: can they support life?
Astrobiology was ready to join in the search for exoplanets.
VPL is based at the University of Washington, but coordinates the research of scientists from many different institutions around the world. (8)
Astrobiology includes scientists from many fields, and so does the VPL.
Planetary scientists
Climatologists
Astronomers.
Geophysicists
Biophysicists
Spectroscopists
Atmospheric chemists
Virologists
Biologists
Geochemists
Molecular evolutionary biologists
Geomicrobiologists
Just to name a few.
Our goal is to take what we have learned about habitability from our own solar system....
...and apply it to extrasolar planets.
We've developed a 'tool kit' of computer models to simulate possible environments on distant worlds.
And we study how observations and modeling can help determine if a planet is (or was) able to support life.
This work helps us determine what to look for with current and future NASA missions.


Understanding habitable planets starts with Earth.
Analog environments on Earth help us study life's potential in the Solar System*.
* See Issue 5
But Earth, the **entire** planet, is like one giant analog for habitable worlds.
Earth science helps us predict what our telescopes might see in other planetary systems.
We also need to understand the Earth through time...
...how it formed, evolved, and became a home for life.
We start our search with **terrestrial** planets.
Now, 'terrestrial' does not mean 'Earth-like' or habitable.
It means the planet is made of metals and rocks.
Our system has four terrestrial planets, but only one with life**.
Mercury
Venus
Earth
Mars
Bodies like the dwarf planet Pluto aren't terrestrial because they have so much ice and frozen material.
**See Issues 2,3 & 5

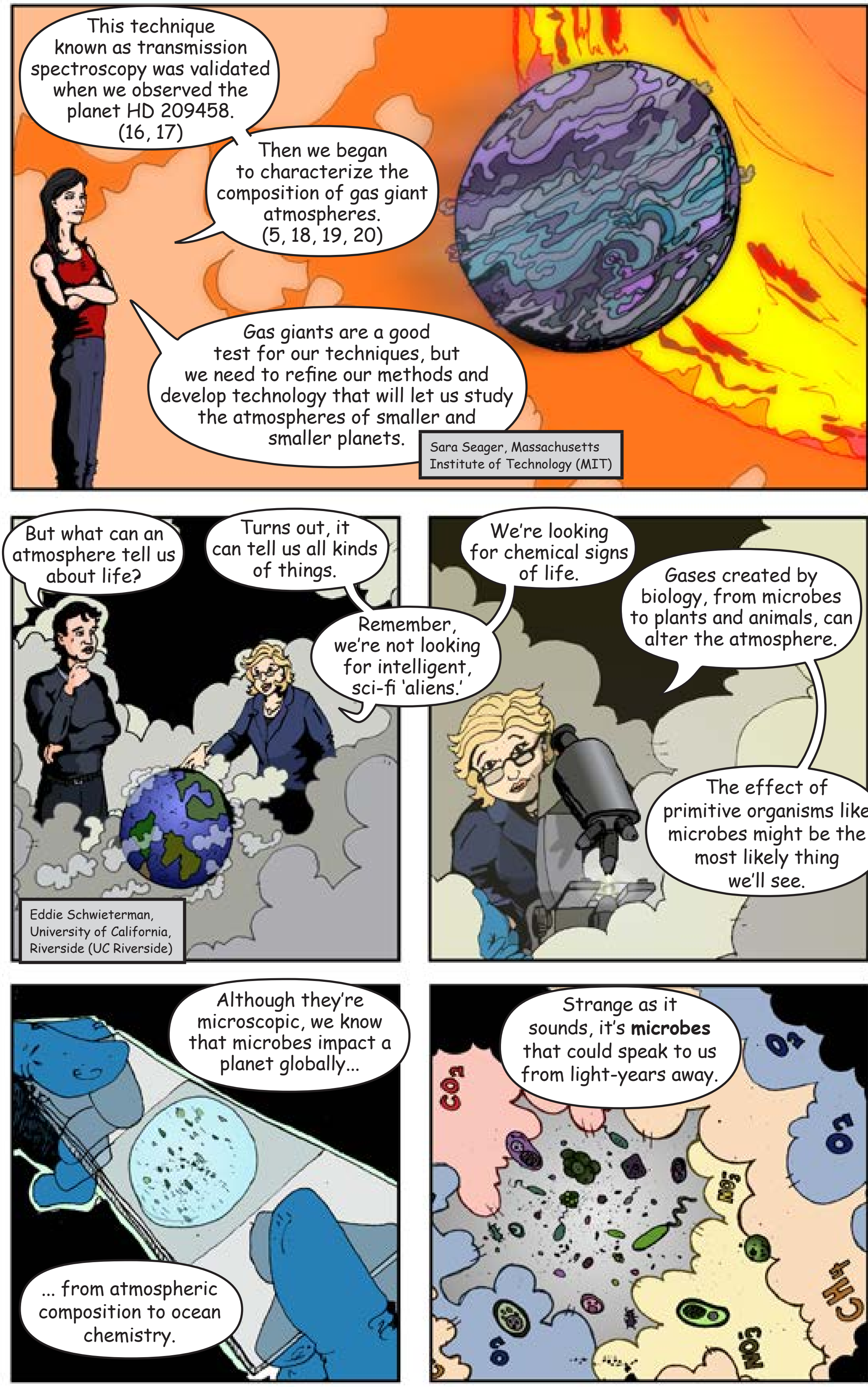


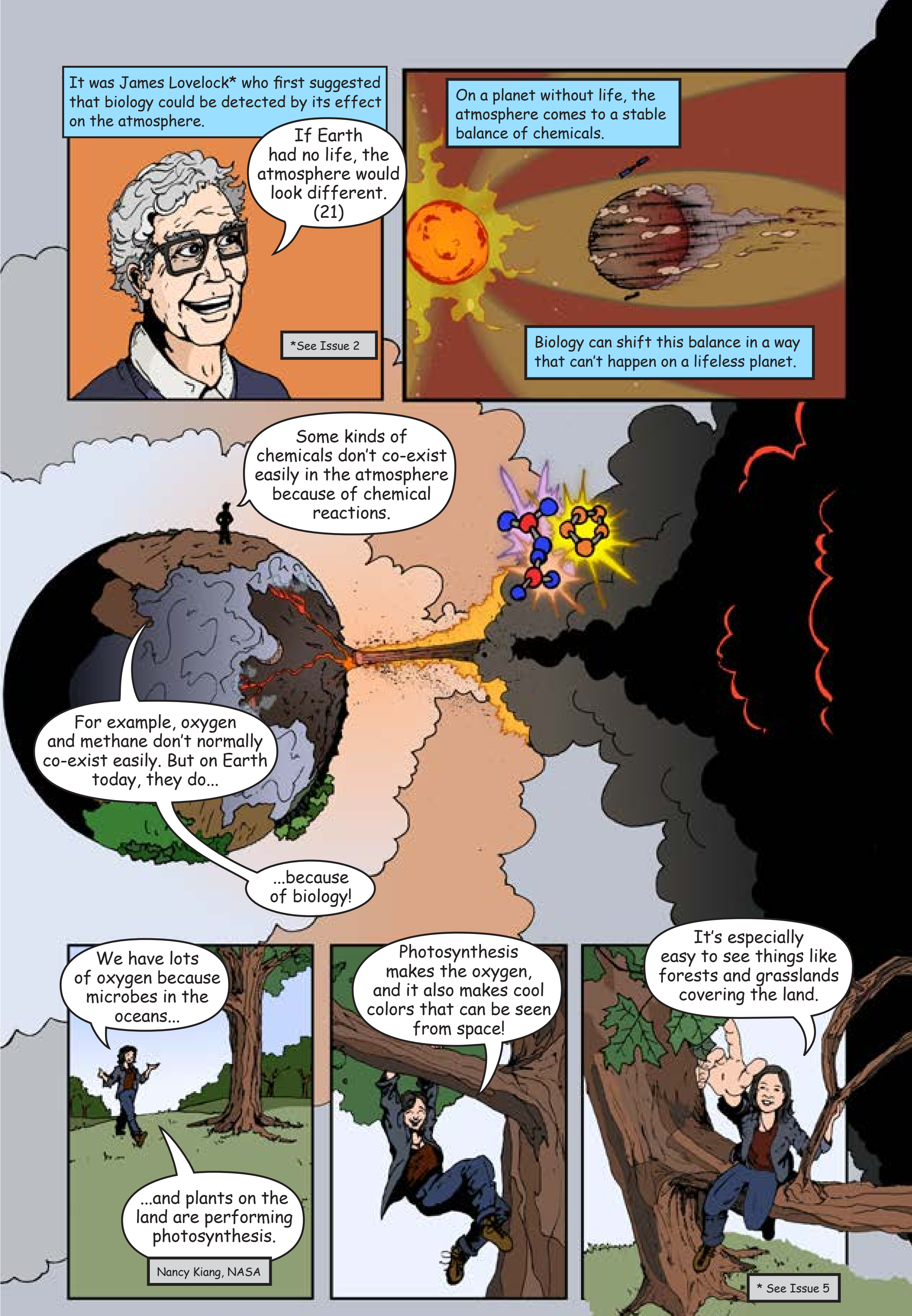
Earth-sized means with a similar diameter to the Earth.
Earth-mass means it has a similar mass.
Just because a planet has the same mass as the Earth doesn't mean its the same size... and vice versa. (9, 10)
Leslie Rogers, University of Chicago
Two planets with the same mass could have different diameters.
5.972x10^24
It just depends on the planet's density...
...in other words, what it is made out of.
Earth is the biggest terrestrial planet in our system, but it's hard to say how big a terrestrial planet in another system could be.
So far, we think it has to be less than 1.6 Earth radii. (11)
That's where you might hit the boundary between rocky 'super Earths', and small gaseous planets we call 'mini-Neptunes'.
Once we find terrestrial planets, the next step is figuring out what they're like.
We start with determining their orbits.


We want to look at small planets. The easiest planets to find with our techniques are ones that orbit close to their star.
Being near the star can make it too hot for life... just look at Mercury.*
We need to be able to spot terrestrial planets further from their stars...
...but not so far that they are too cold for life.**
Early on, scientists came up with the simple idea of the 'habitable' or 'Goldilocks' zone by looking at our own system. (12)
This is the zone where liquid water can exist on the surface of a planet.
*See Issue 3
**See Issues 4 and 5
The habitable zone is not too hot, and not too cold...
...it's just right to support liquid water on the surface, which is essential for life as we know it.*
*Official definition of the habitable zone.
That doesn't sound too hard. We look for a planet just like Earth.
Same diameter, same mass, same orbit.
After all, Earth is the only planet we know with life.
Or is it...

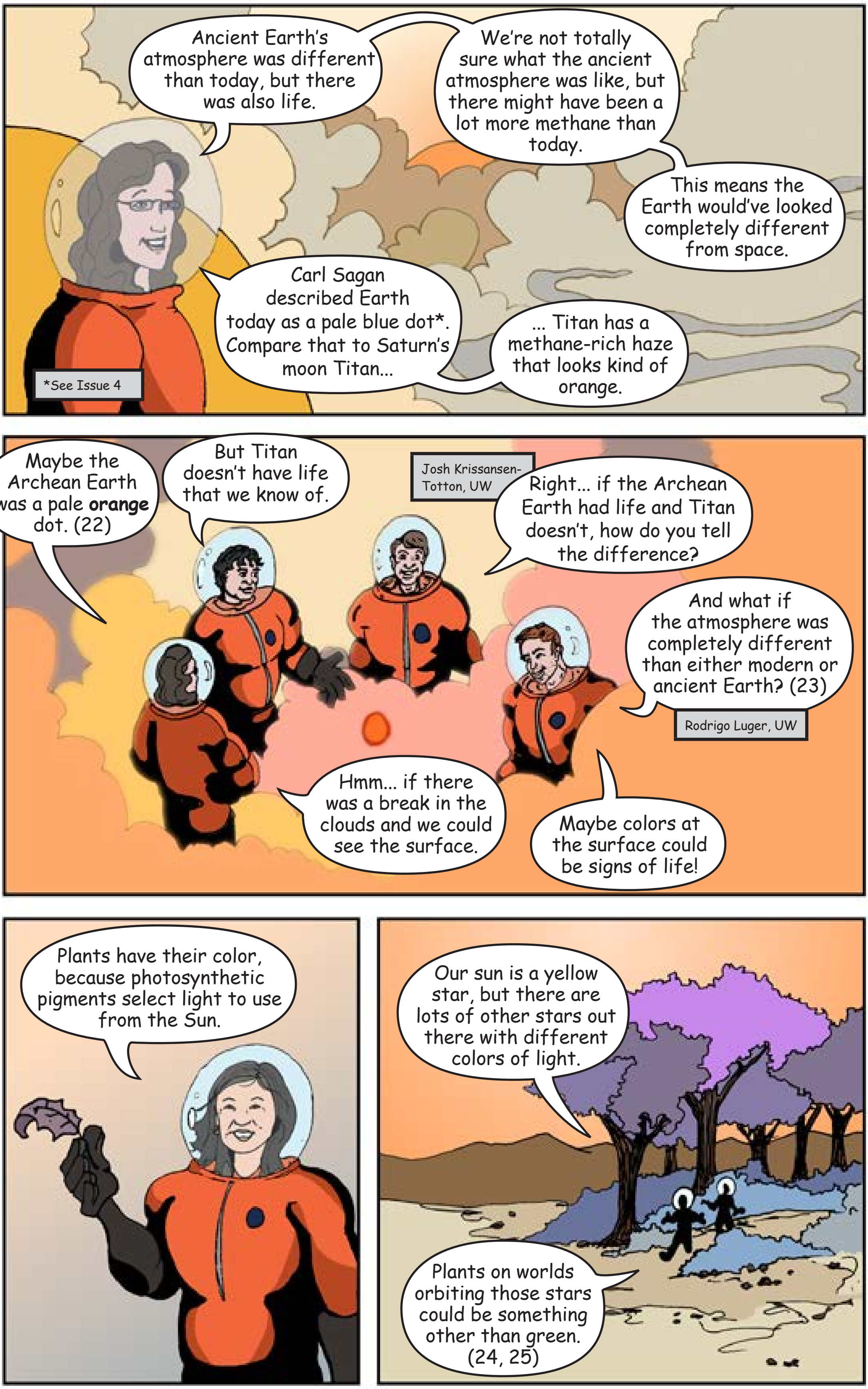

In some ways, Earth isn't the only analog we have for an inhabited world.
Maybe Earth-like exoplanets don't have to look like the Earth we know **today**.
PFFFT
Remember, we must understand the Earth **through time**.
Life has been on Earth for **billions** of years and, long ago, the planet looked a lot different.
For so much of its history, Earth didn't even have an 'oxygen' atmosphere.
The most 'alien' planet that we have data for is actually the ancient Earth...
The Earth: today.
The Earth: 4 billion years ago.
...which we study through geochemistry and geology.
Maybe there's an inhabited planet that looks more like the Archean Earth (4 billion to 2.5 billion years ago)...
...when life first originated! (13)

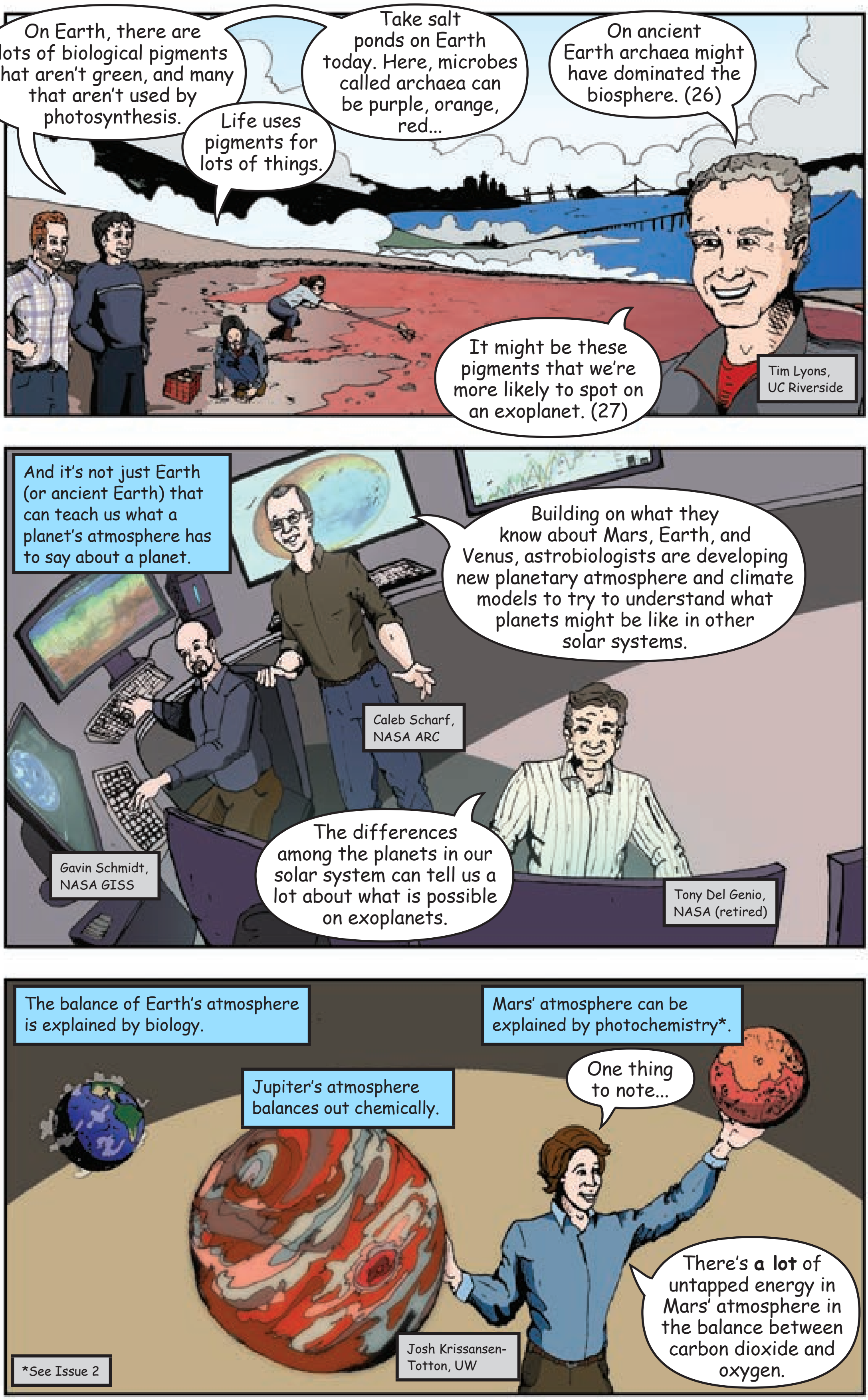

Ignas Snellen, Leiden University
We just need to find the right planet to study, and put these ideas to the test!
That's a big challenge. Exo-planets are so **far away**.
But we can still study a planet, even though we can't see it.
Drake Deming, University of Maryland at College Park
What do you mean by that?
When a planet passes in front of a star it blocks some of the star's light.
If we are careful, we can see some of that light filtered by a planet's atmosphere.
We separate the **tiny** amount of light that makes it through the atmosphere from the **huge** amount of light you see from the star. (14)
It's tough, but our techniques are getting better and better.
As light passes through the planet's atmosphere, the gas changes what it looks like to us.
Different gas molecules absorb light at different wavelengths.
Sara Seager, MIT
Dimitar Sasselov, Harvard University
We see those changes in the star's transmission spectrum. The trick is figuring out what they mean.
First, we made models to help determine **how** we could study the atmospheres of transiting planets. (15)


This technique known as transmission spectroscopy was validated when we observed the planet HD 209458. (16, 17)
Then we began to characterize the composition of gas giant atmospheres. (5, 18, 19, 20)
Gas giants are a good test for our techniques, but we need to refine our methods and develop technology that will let us study the atmospheres of smaller and smaller planets.
Sara Seager, Massachusetts Institute of Technology (MIT)
But what can an atmosphere tell us about life?
Turns out, it can tell us all kinds of things.
Remember, we're not looking for intelligent, sci-fi 'aliens.'
Eddie Schwieterman, University of California, Riverside (UC Riverside)
We're looking for chemical signs of life.
Gases created by biology, from microbes to plants and animals, can alter the atmosphere.
The effect of primitive organisms like microbes might be the most likely thing we'll see.
Although they're microscopic, we know that microbes impact a planet globally...
... from atmospheric composition to ocean chemistry.
Strange as it sounds, it's **microbes** that could speak to us from light-years away.
CO_2
O_2
O_3
CH_4

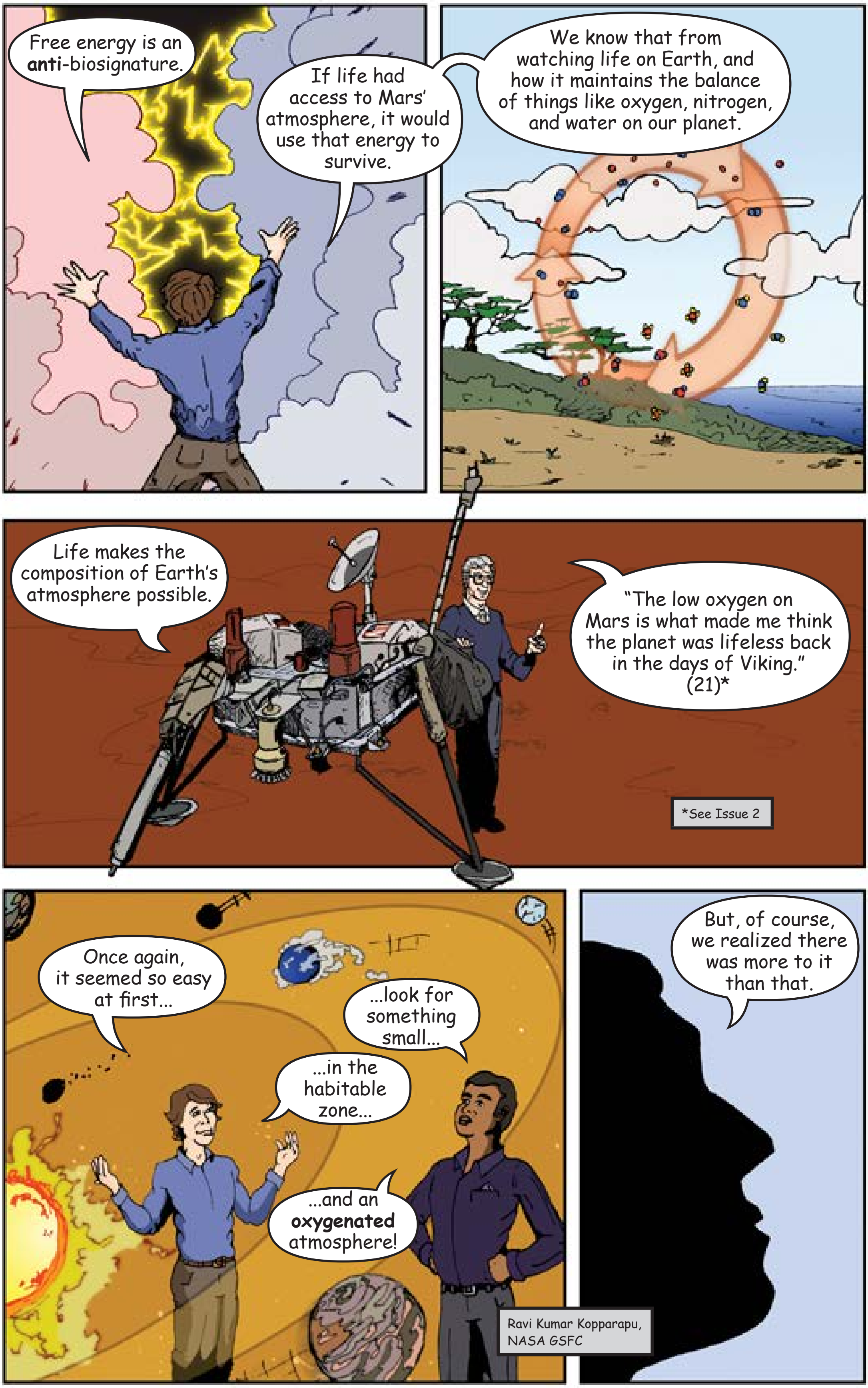


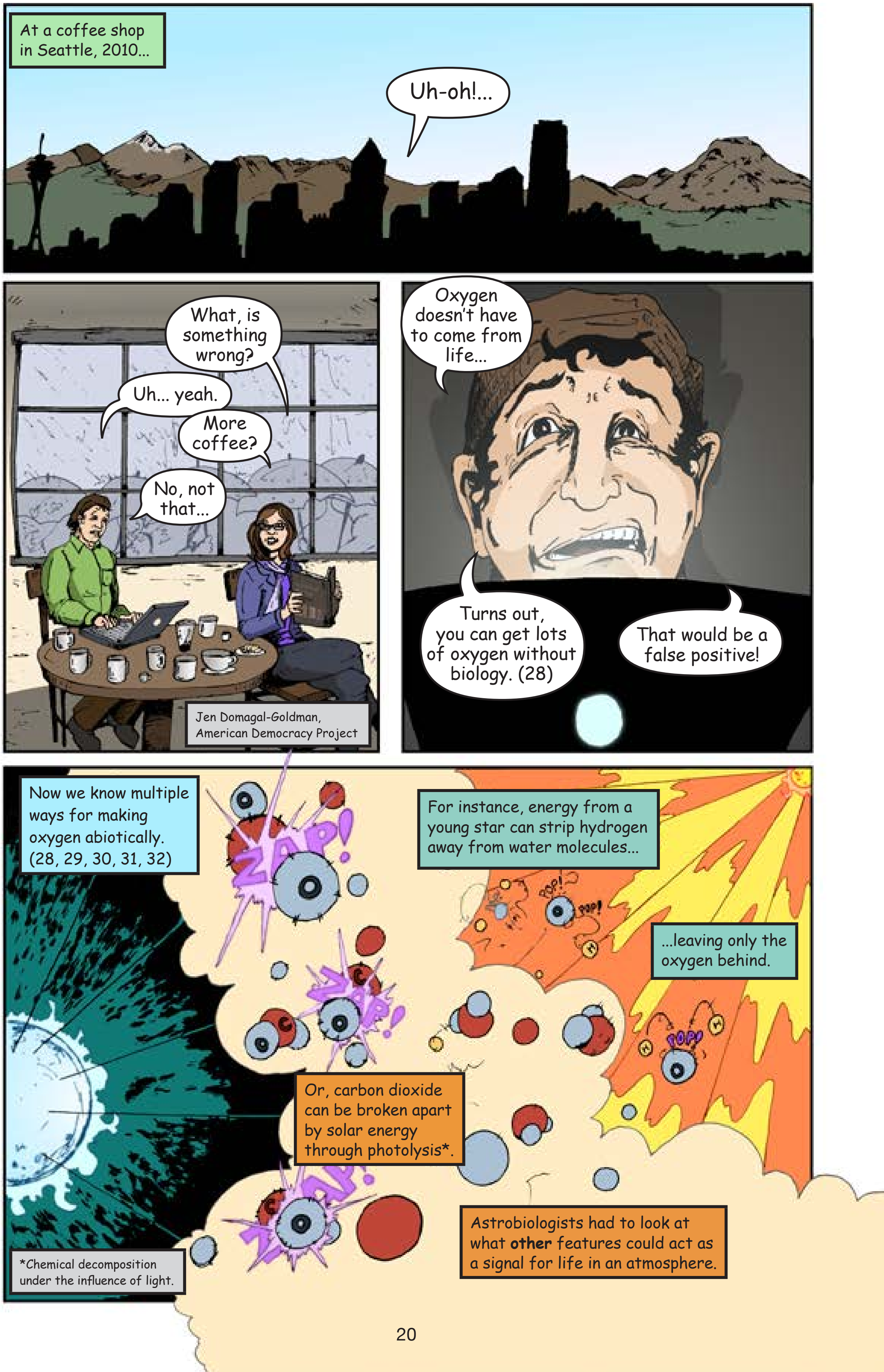
It was James Lovelock* who first suggested that biology could be detected by its effect on the atmosphere.
If Earth had no life, the atmosphere would look different. (21)
*See Issue 2
On a planet without life, the atmosphere comes to a stable balance of chemicals.
Biology can shift this balance in a way that can't happen on a lifeless planet.
Some kinds of chemicals don't co-exist easily in the atmosphere because of chemical reactions.
For example, oxygen and methane don't normally co-exist easily. But on Earth today, they do...
...because of biology!
We have lots of oxygen because microbes in the oceans...
...and plants on the land are performing photosynthesis.
Nancy Kiang, NASA
Photosynthesis makes the oxygen, and it also makes cool colors that can be seen from space!
It's especially easy to see things like forests and grasslands covering the land.
* See Issue 5


Ancient Earth's atmosphere was different than today, but there was also life.
We're not totally sure what the ancient atmosphere was like, but there might have been a lot more methane than today.
This means the Earth would've looked completely different from space.
Carl Sagan described Earth today as a pale blue dot*. Compare that to Saturn's moon Titan...
... Titan has a methane-rich haze that looks kind of orange.
*See Issue 4
Maybe the Archean Earth was a pale **orange** dot. (22)
But Titan doesn't have life that we know of.
Josh Krissansen-Totton, UW
Right... if the Archean Earth had life and Titan doesn't, how do you tell the difference?
And what if the atmosphere was completely different than either modern or ancient Earth? (23)
Rodrigo Luger, UW
Hmm... if there was a break in the clouds and we could see the surface.
Maybe colors at the surface could be signs of life!
Plants have their color, because photosynthetic pigments select light to use from the Sun.
Our sun is a yellow star, but there are lots of other stars out there with different colors of light.
Plants on worlds orbiting those stars could be something other than green. (24, 25)

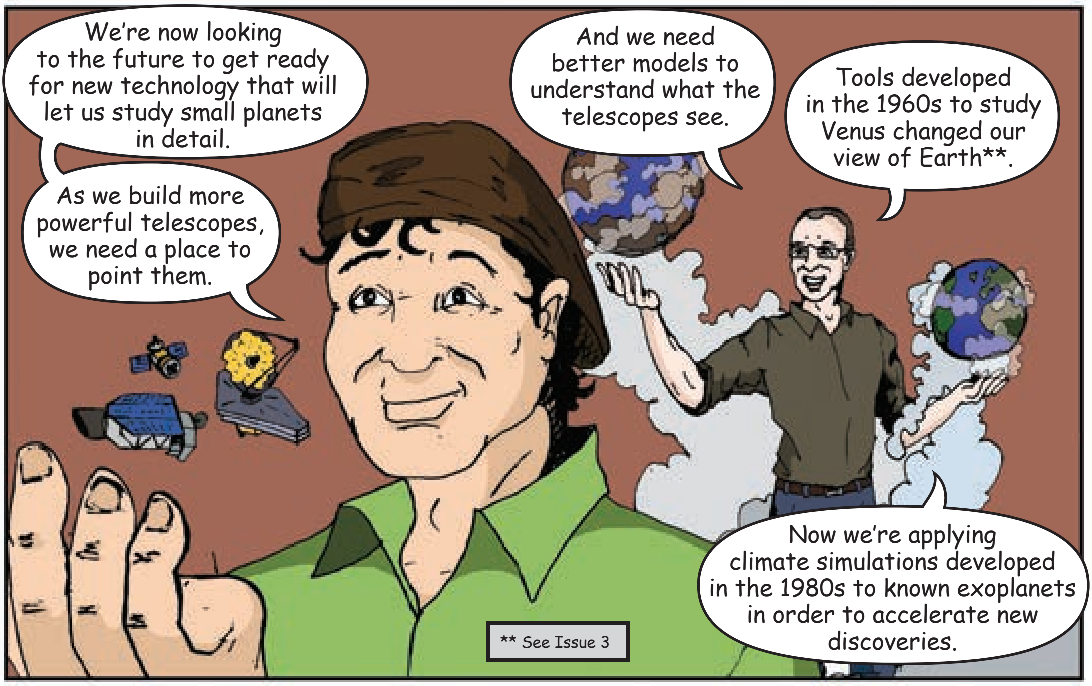


On Earth, there are lots of biological pigments that aren't green, and many that aren't used by photosynthesis.
Life uses pigments for lots of things.
Take salt ponds on Earth today. Here, microbes called archaea can be purple, orange, red...
On ancient Earth archaea might have dominated the biosphere. (26)
It might be these pigments that we're more likely to spot on an exoplanet. (27)
Tim Lyons, UC Riverside
And it's not just Earth (or ancient Earth) that can teach us what a planet's atmosphere has to say about a planet.
Building on what they know about Mars, Earth, and Venus, astrobiologists are developing new planetary atmosphere and climate models to try to understand what planets might be like in other solar systems.
Caleb Scharf, NASA ARC
The differences among the planets in our solar system can tell us a lot about what is possible on exoplanets.
Gavin Schmidt, NASA GISS
Tony Del Genio, NASA (retired)
The balance of Earth's atmosphere is explained by biology.
Mars' atmosphere can be explained by photochemistry*.
Jupiter's atmosphere balances out chemically.
One thing to note...
There's **a lot** of untapped energy in Mars' atmosphere in the balance between carbon dioxide and oxygen.
Josh Krissansen-Totton, UW
*See Issue 2


Free energy is an **anti**-biosignature.
If life had access to Mars' atmosphere, it would use that energy to survive.
We know that from watching life on Earth, and how it maintains the balance of things like oxygen, nitrogen, and water on our planet.
Life makes the composition of Earth's atmosphere possible.
"The low oxygen on Mars is what made me think the planet was lifeless back in the days of Viking." (21)*
*See Issue 2
Once again, it seemed so easy at first...
...look for something small...
...in the habitable zone...
...and an **oxygenated** atmosphere!
Ravi Kumar Kopparapu, NASA GSFC
But, of course, we realized there was more to it than that.

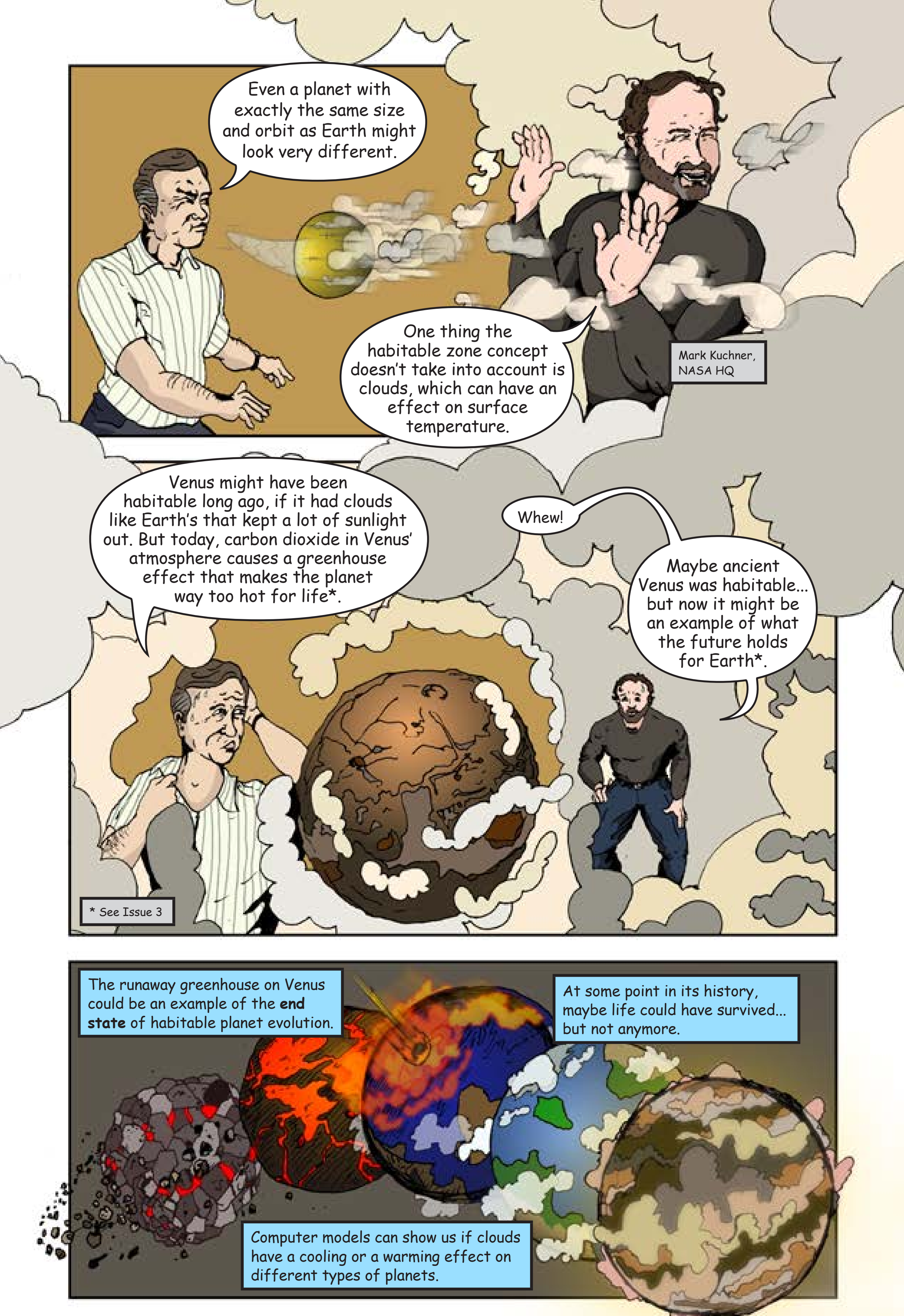

At a coffee shop in Seattle, 2010...
Uh-oh!...
What, is something wrong?
Uh... yeah.
More coffee?
No, not that...
Jen Domagal-Goldman, American Democracy Project
Oxygen doesn't have to come from life...
Turns out, you can get lots of oxygen without biology. (28)
That would be a false positive!
Now we know multiple ways for making oxygen abiotically. (28, 29, 30, 31, 32)
ZAP!
For instance, energy from a young star can strip hydrogen away from water molecules...
...leaving only the oxygen behind.
POP!
ZAP!
Or, carbon dioxide can be broken apart by solar energy through photolysis*.
ZAP!
Astrobiologists had to look at what **other** features could act as a signal for life in an atmosphere.
*Chemical decomposition under the influence of light.

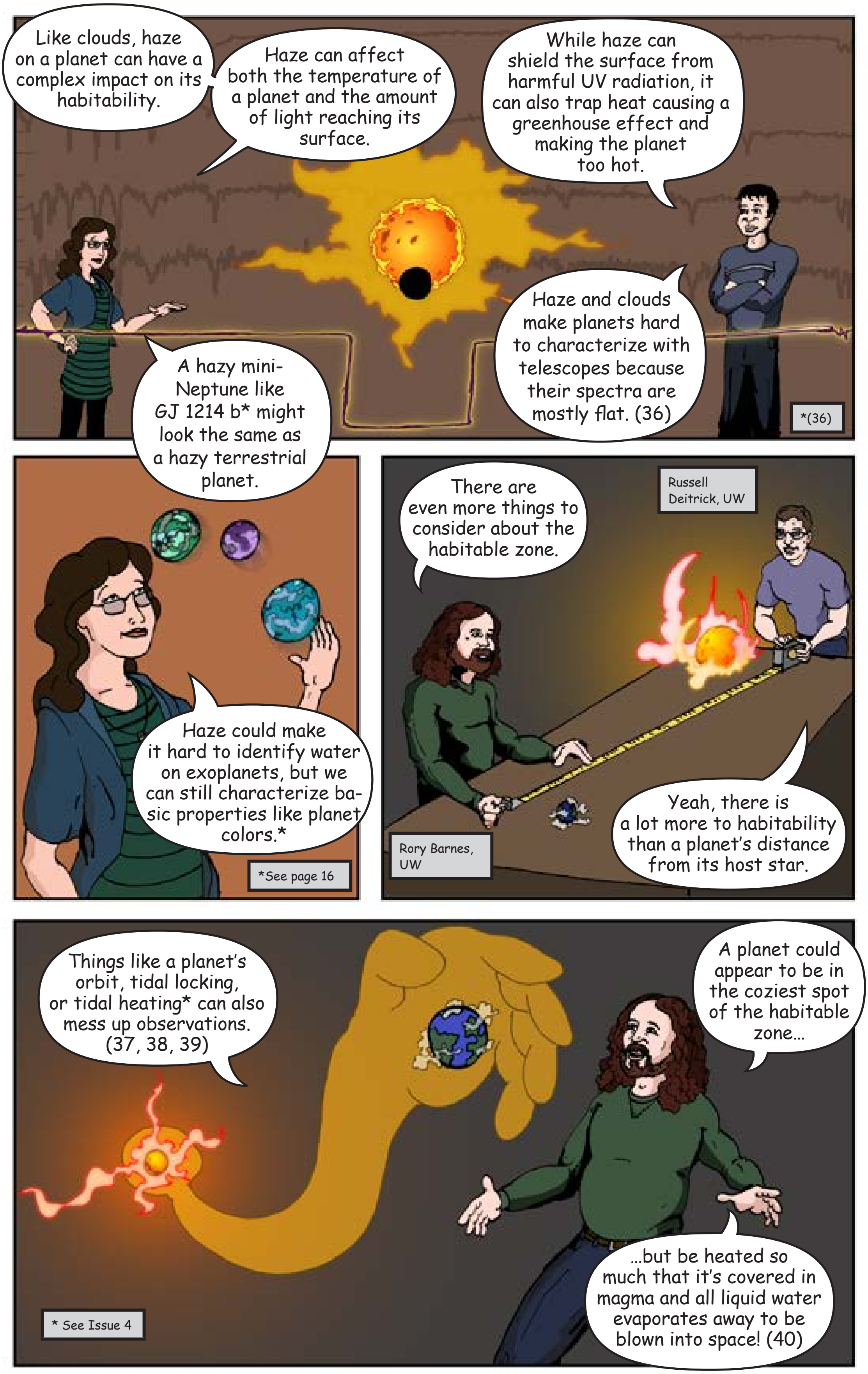

If the oxygen comes from photolysis, or some other process...
...maybe something else happens alongside that process that we can detect?
Then we could tell the difference between oxygen from biology, and oxygen from something else.
We realized that we can't only think about how to identify life.
We also need to think about how we might be fooled.
Cecilia Bitz, UW
The more complicated our questions got, the more scientists we needed to try and answer them.
Exactly.
It was time to get insights from an even wider scientific community.
Rika Anderson, Carleton College
In 2014, NASA Astrobiology led an effort to create a new, coordinated network of exoplanet explorers.
It was dubbed the Nexus for Exoplanet System Science (NExSS)*. (33)
NExSS encourages collaboration among the four science communities supported by NASA's Science Mission Directorate.
Earth Science
Astrophysics
Heliophysics
Planetary Science.
* Check out other NASA Research Coordination Networks (RCNs) in other issues!

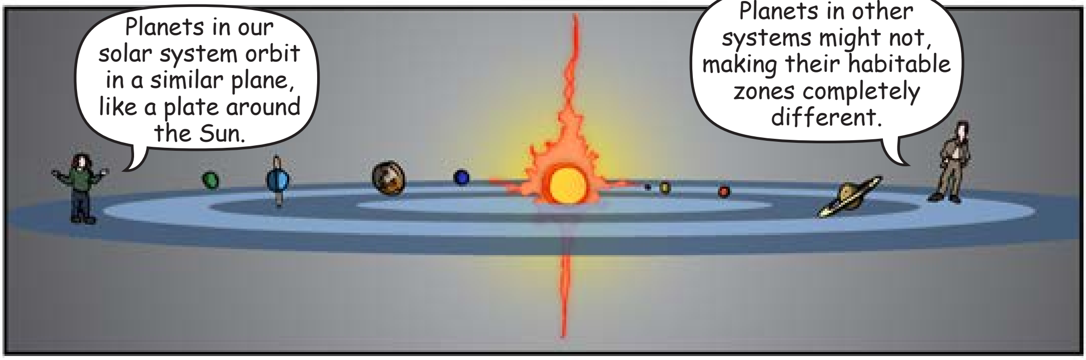

We're now looking to the future to get ready for new technology that will let us study small planets in detail.
As we build more powerful telescopes, we need a place to point them.
And we need better models to understand what the telescopes see.
Tools developed in the 1960s to study Venus changed our view of Earth**.
Now we're applying climate simulations developed in the 1980s to known exoplanets in order to accelerate new discoveries.
** See Issue 3


NExSS includes several research teams, each dedicated to solving a piece of the exoplanet puzzle.
NExSS research covers every aspect of habitability, from planet formation to the end of a planet's lifecycle.
With a growing community of astronomers, astrophysicists, Earth scientists and heliophysicists at NASA working together, we're developing an even deeper understanding of how planets evolve...
...how they might be like or unlike Earth...
...how they interact with their stars...
...and their past or present habitability.
Eric Ford, Penn State
Steve Desch, Arizona State University

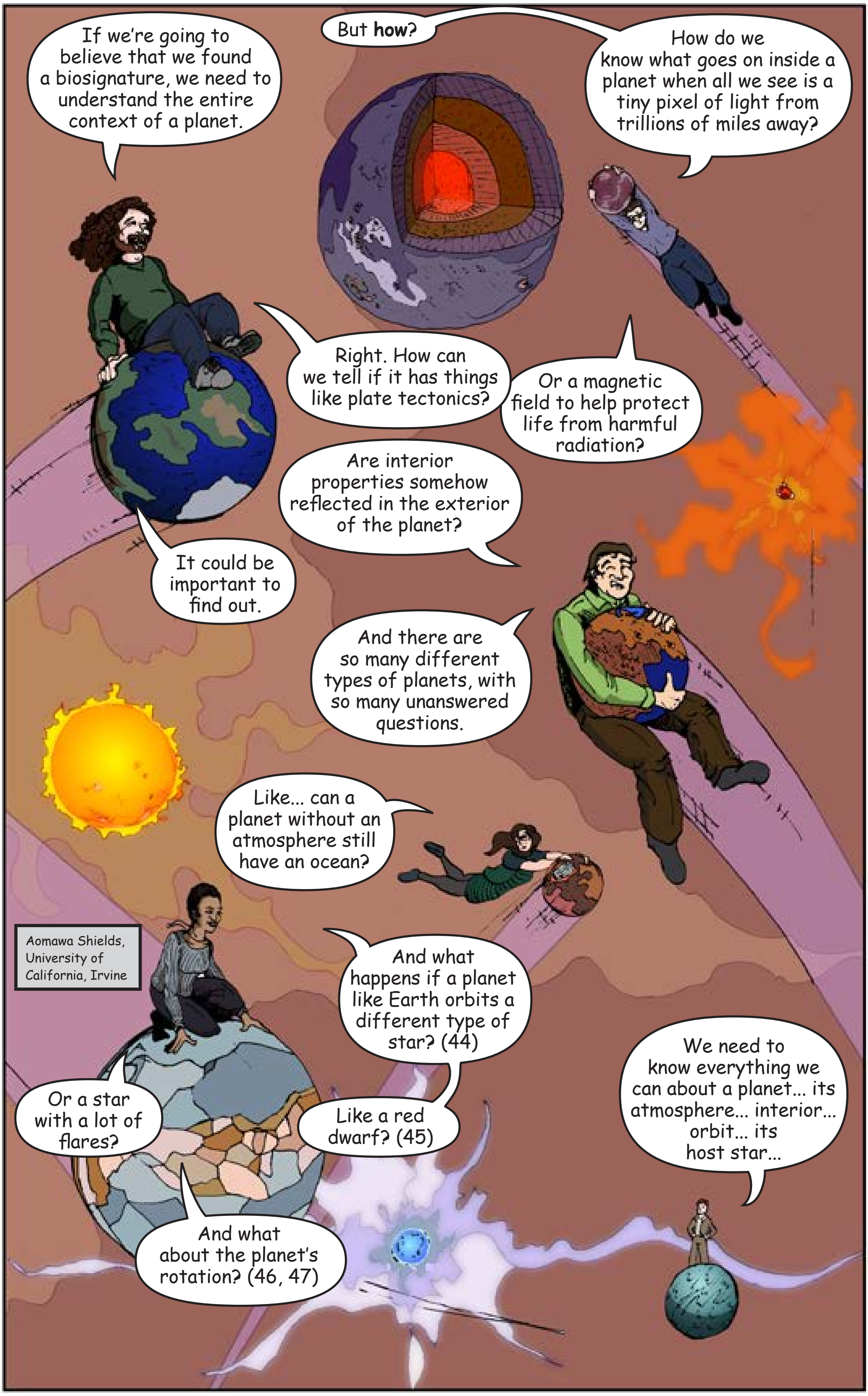

With new ideas from even more scientists, let's look again at the 'habitable zone.'
The definition of "habitable zone" is the distance from a star at which liquid water could exist on surfaces of orbiting planets. (34, 35)
The 'habitable zone' makes things sound easy. We just need a small planet with an orbit similar to the Earth.
If only it were that simple...
The habitable zone is based on an Earth-like planet, with an Earth-like atmosphere.
As soon as a planet deviates from that composition, it can get into trouble.
Antígona Segura Peralta, Universidad Nacional Autónoma de México
Mars is at the outer edge of our system's habitable zone.
Earth sits in the middle.
Venus is outside the habitable zone, but it's close to the inner limit.
So far, we haven't found evidence of past or present life on either Mars or Venus.
And what about the Moon? It sits within our system's habitable zone, yet it isn't habitable.
So you see, there's more to it than spotting a world in the habitable zone.

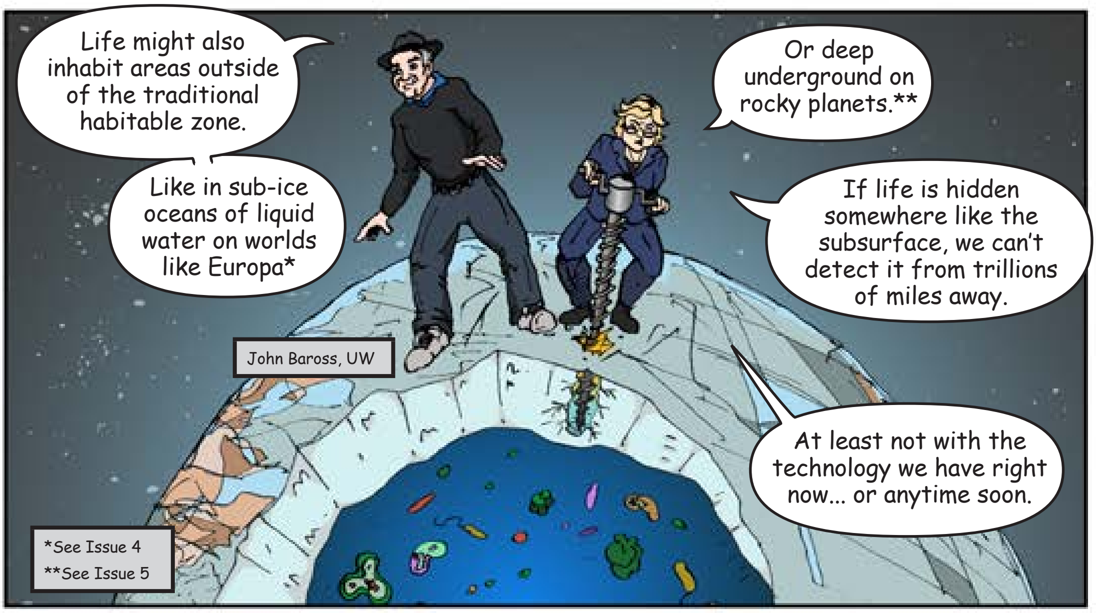

Even a planet with exactly the same size and orbit as Earth might look very different.
One thing the habitable zone concept doesn't take into account is clouds, which can have an effect on surface temperature.
Mark Kuchner, NASA HQ
Venus might have been habitable long ago, if it had clouds like Earth's that kept a lot of sunlight out. But today, carbon dioxide in Venus' atmosphere causes a greenhouse effect that makes the planet way too hot for life*.
Whew!
Maybe ancient Venus was habitable... but now it might be an example of what the future holds for Earth*.
* See Issue 3
The runaway greenhouse on Venus could be an example of the **end state** of habitable planet evolution.
At some point in its history, maybe life could have survived... but not anymore.
Computer models can show us if clouds have a cooling or a warming effect on different types of planets.

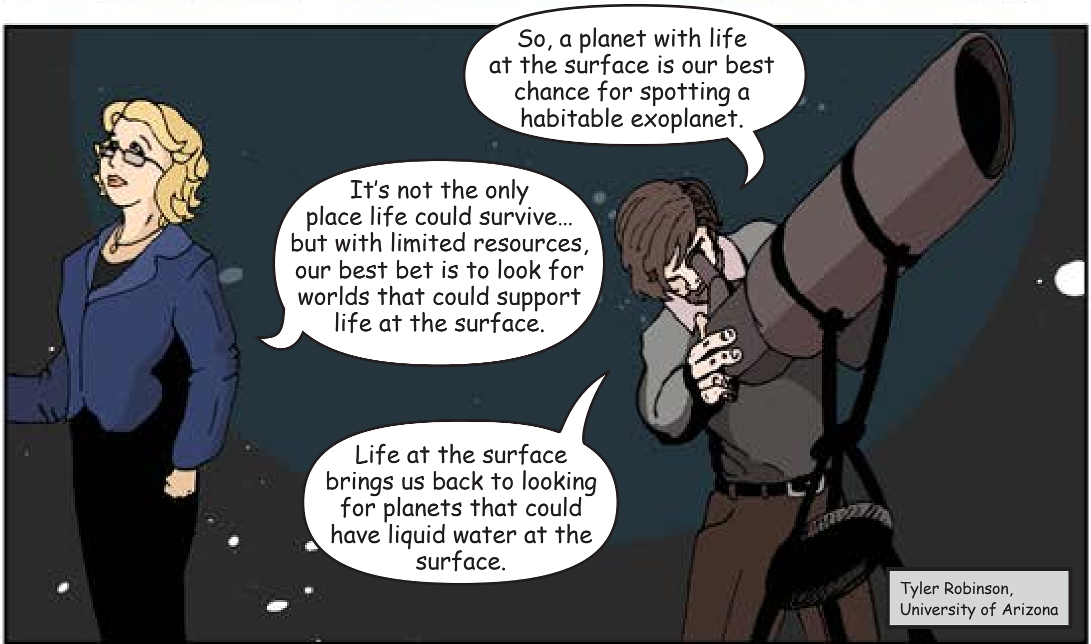

Like clouds, haze on a planet can have a complex impact on its habitability.
Haze can affect both the temperature of a planet and the amount of light reaching its surface.
While haze can shield the surface from harmful UV radiation, it can also trap heat causing a greenhouse effect and making the planet too hot.
A hazy mini-Neptune like GJ 1214 b* might look the same as a hazy terrestrial planet.
Haze and clouds make planets hard to characterize with telescopes because their spectra are mostly flat. (36)
*(36)
Haze could make it hard to identify water on exoplanets, but we can still characterize basic properties like planet colors.*
*See page 16
There are even more things to consider about the habitable zone.
Russell Deitrick, UW
Rory Barnes, UW
Yeah, there is a lot more to habitability than a planet's distance from its host star.
Things like a planet's orbit, tidal locking, or tidal heating* can also mess up observations. (37, 38, 39)
A planet could appear to be in the coziest spot of the habitable zone...
...but be heated so much that it's covered in magma and all liquid water evaporates away to be blown into space! (40)
* See Issue 4

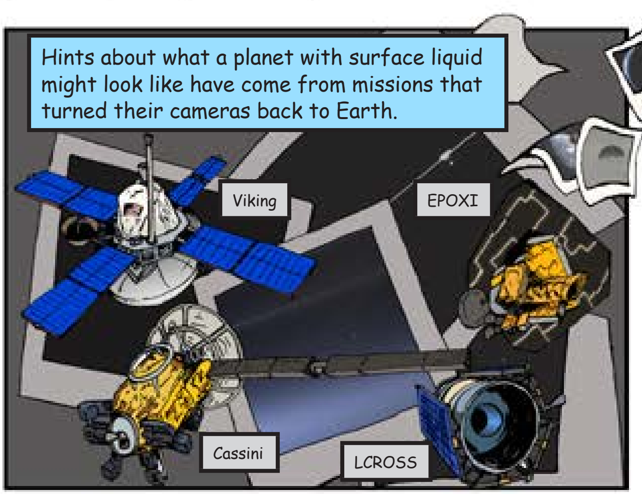

Planets in our solar system orbit in a similar plane, like a plate around the Sun.
Planets in other systems might not, making their habitable zones completely different.

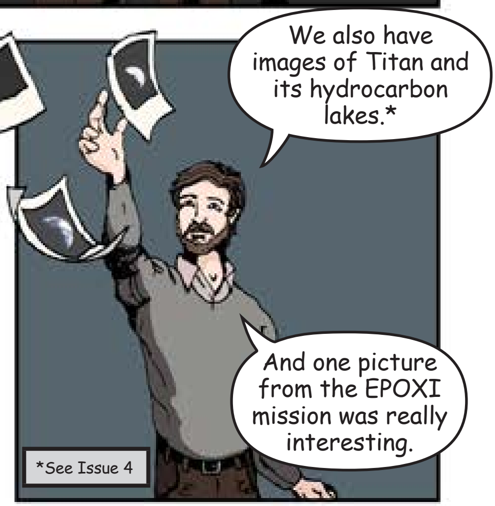

A planet on a crazy orbit might transit its star...
... which means we can spot it...
...but because of gravitational interactions between planets and stars in the system, it might swing both so far away from and so close to its star that it is uninhabitable for life as we know it. (41)
Whoa!
WHOOSH!!!
This is where orbital dynamics can affect the climate and habitability of a planet.
If the orbit isn't circular, a planet could cook part of the time... and freeze for the other part! (42, 43)
Eric Agol, UW


If we're going to believe that we found a biosignature, we need to understand the entire context of a planet.
But **how**?
How do we know what goes on inside a planet when all we see is a tiny pixel of light from trillions of miles away?
Right. How can we tell if it has things like plate tectonics?
Or a magnetic field to help protect life from harmful radiation?
Are interior properties somehow reflected in the exterior of the planet?
It could be important to find out.
And there are so many different types of planets, with so many unanswered questions.
Like... can a planet without an atmosphere still have an ocean?
Aomawa Shields, University of California, Irvine
And what happens if a planet like Earth orbits a different type of star? (44)
Like a red dwarf? (45)
Or a star with a lot of flares?
And what about the planet's rotation? (46, 47)
We need to know everything we can about a planet... its atmosphere... interior... orbit... its host star...

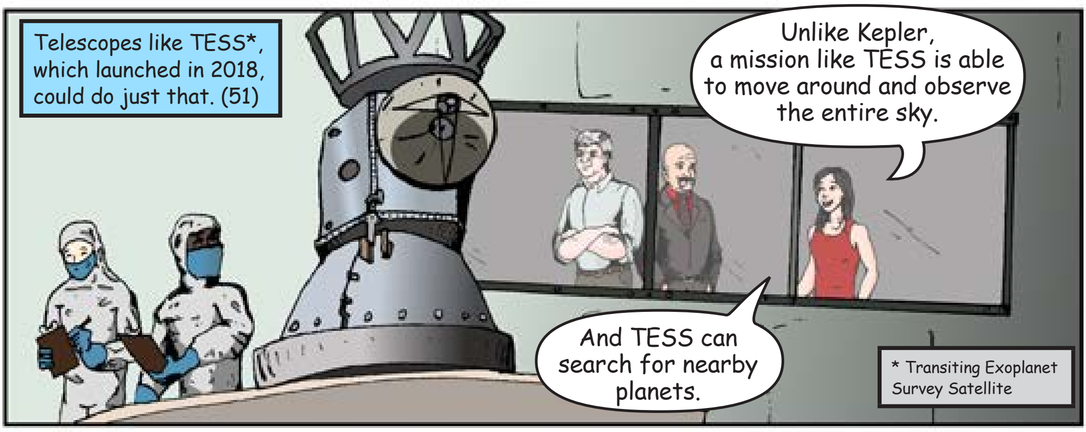

Life might also inhabit areas outside of the traditional habitable zone.
Like in sub-ice oceans of liquid water on worlds like Europa*
Or deep underground on rocky planets.**
If life is hidden somewhere like the subsurface, we can't detect it from trillions of miles away.
At least not with the technology we have right now... or anytime soon.
John Baross, UW
*See Issue 4
**See Issue 5

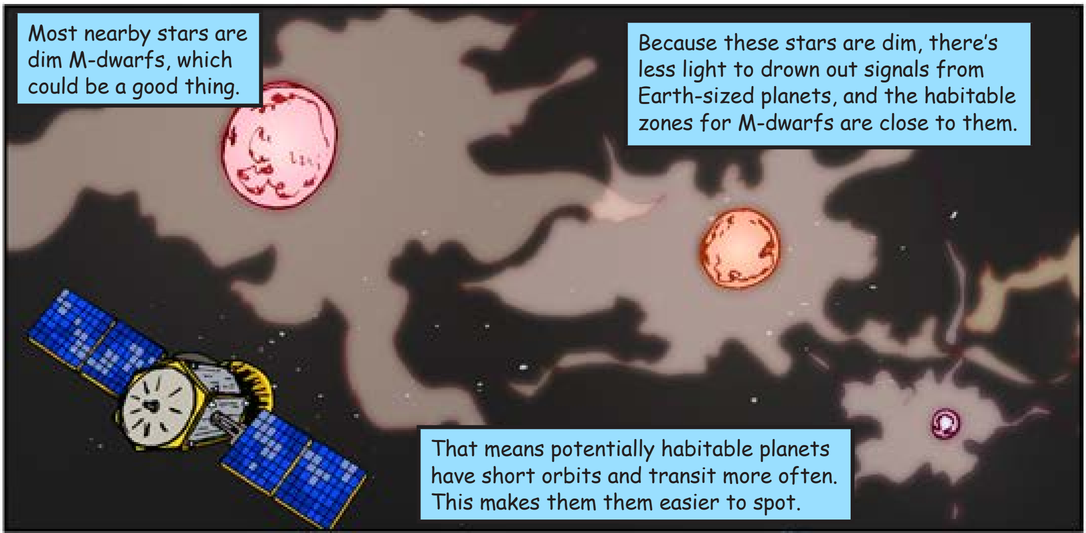

So, a planet with life at the surface is our best chance for spotting a habitable exoplanet.
It's not the only place life could survive... but with limited resources, our best bet is to look for worlds that could support life at the surface.
Life at the surface brings us back to looking for planets that could have liquid water at the surface.
Tyler Robinson, University of Arizona

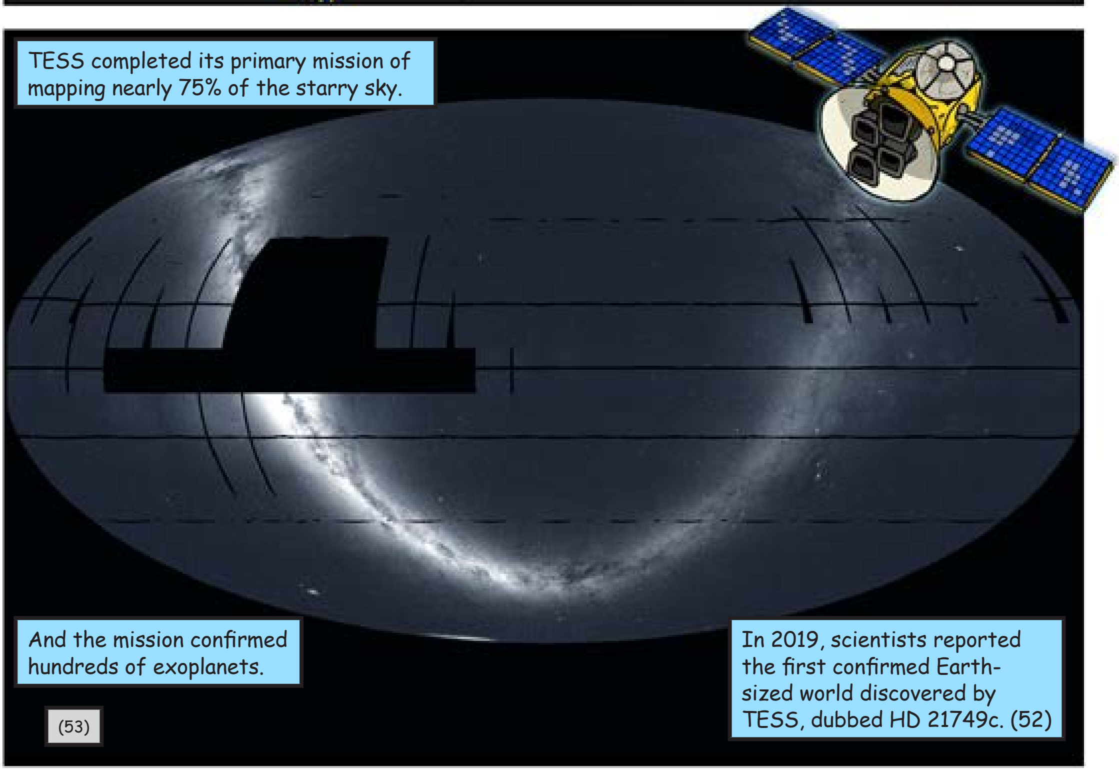

Hints about what a planet with surface liquid might look like have come from missions that turned their cameras back to Earth.
Viking
EPOXI
Cassini
LCROSS

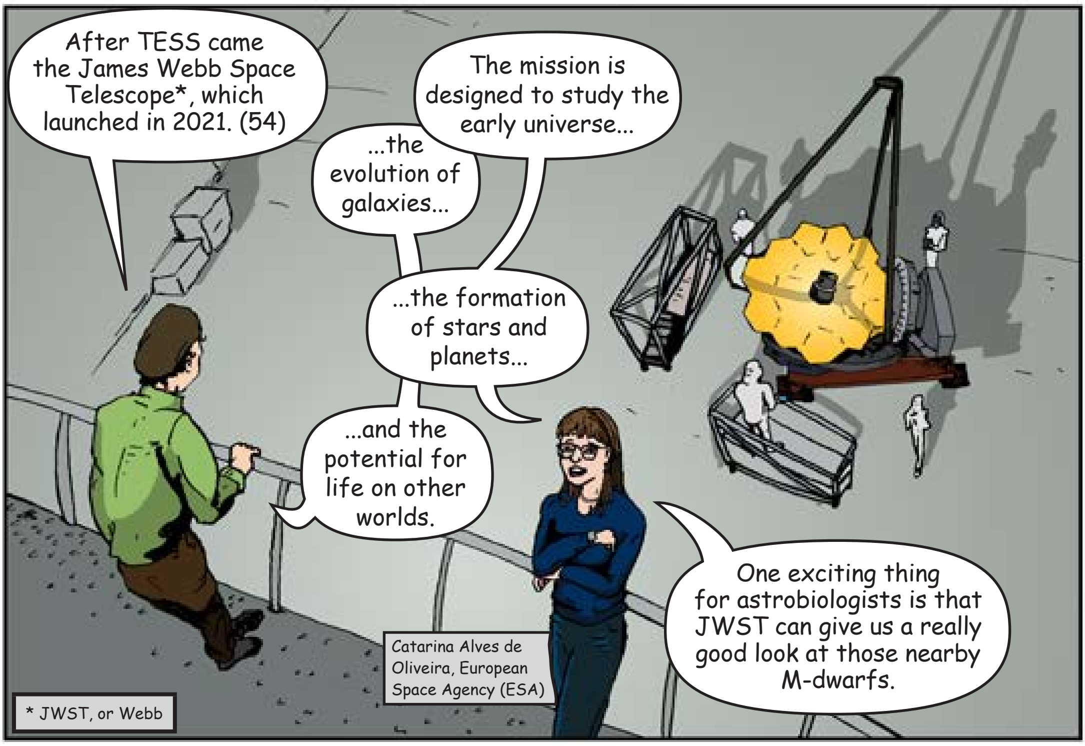

We also have images of Titan and its hydrocarbon lakes.*
And one picture from the EPOXI mission was really interesting.
*See Issue 4

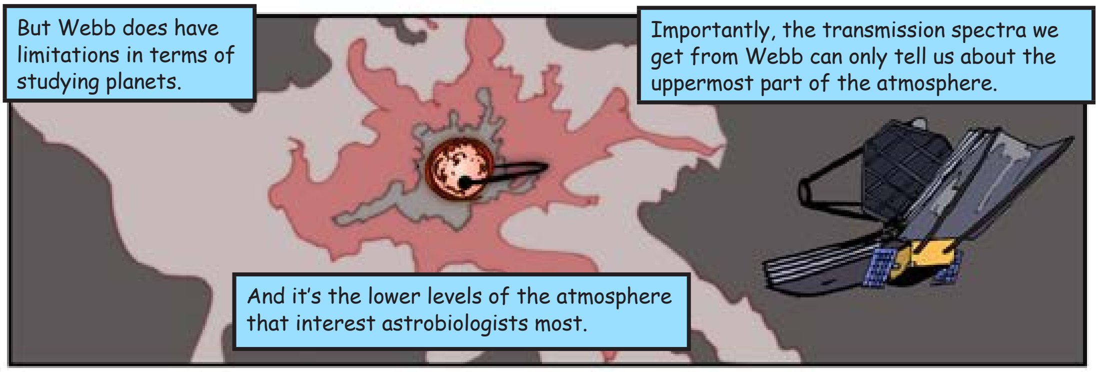

While orbiting Saturn, the Cassini spacecraft caught a glint of light... (48)
...reflecting off of the surface of a hydrocarbon lake on Titan.
EPOXI* caught a bright glint of sunlight reflecting off of bodies of water on Earth's surface. (49)
* Extrasolar Planet Observation and Deep Impact Extended Investigation
Could we detect a similar glint of light with our telescopes? (50)
It wouldn't prove there's life, but liquid is a big step.
Maybe...
... such a tiny amount of light added to the light of the star...
Ralf Jaumann, Deutsches Zentrum für Luft- und Raumfahrt (DLR)
It would certainly help us narrow our search.
Particularly if the liquid is **water**.
Surface water could mean life at the surface.
Where we might stand a chance of detecting it!
Our best hope right now is to find a planet with surface water...
...and focus on looking for life that uses the dominant energy source at the surface...
... light from its star!
That's a scenario that could produce a biosignature in a planet's atmosphere that we could detect with upcoming missions.

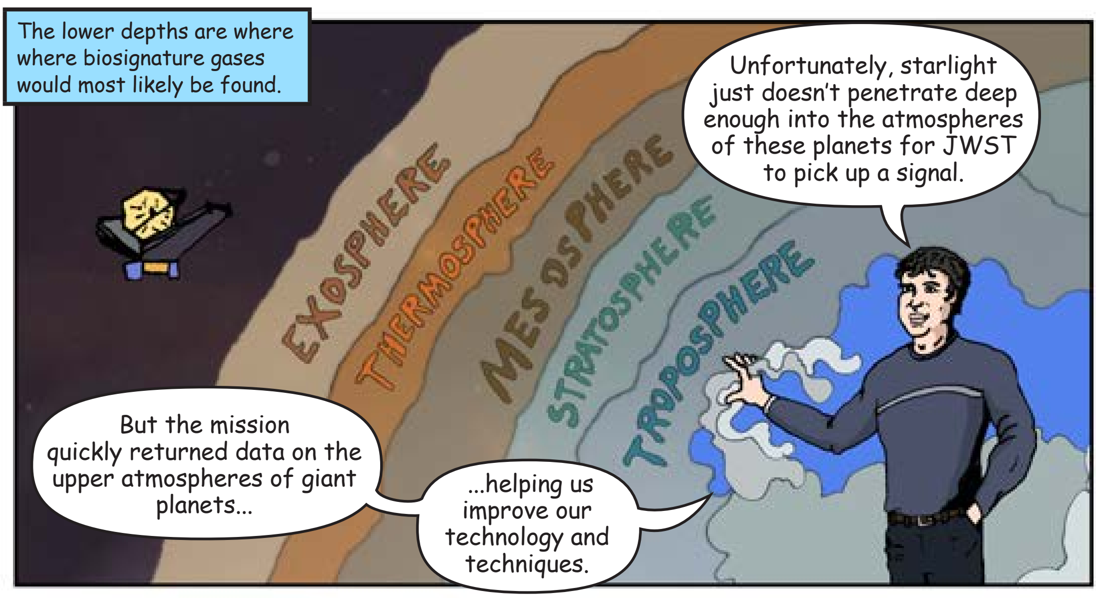

Telescopes like TESS*, which launched in 2018, could do just that. (51)
Unlike Kepler, a mission like TESS is able to move around and observe the entire sky.
And TESS can search for nearby planets.
* Transiting Exoplanet Survey Satellite


Most nearby stars are dim M-dwarfs, which could be a good thing.
Because these stars are dim, there's less light to drown out signals from Earth-sized planets, and the habitable zones for M-dwarfs are close to them.
That means potentially habitable planets have short orbits and transit more often. This makes them them easier to spot.

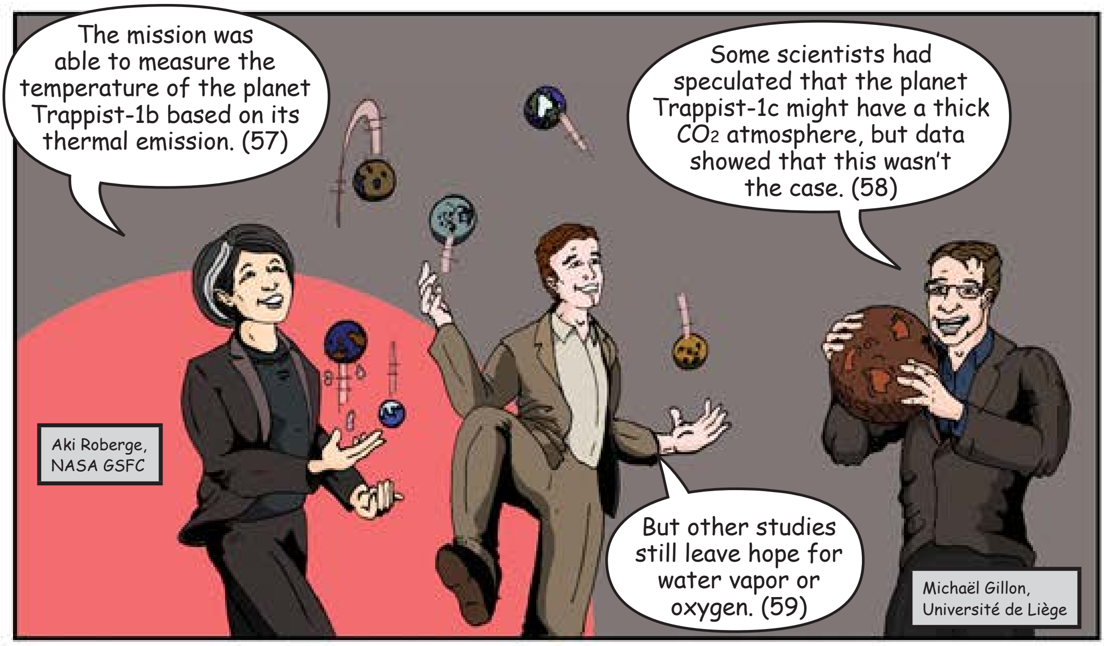

TESS completed its primary mission of mapping nearly 75% of the starry sky.
And the mission confirmed hundreds of exoplanets.
(53)
In 2019, scientists reported the first confirmed Earth-sized world discovered by TESS, dubbed HD 21749c. (52)

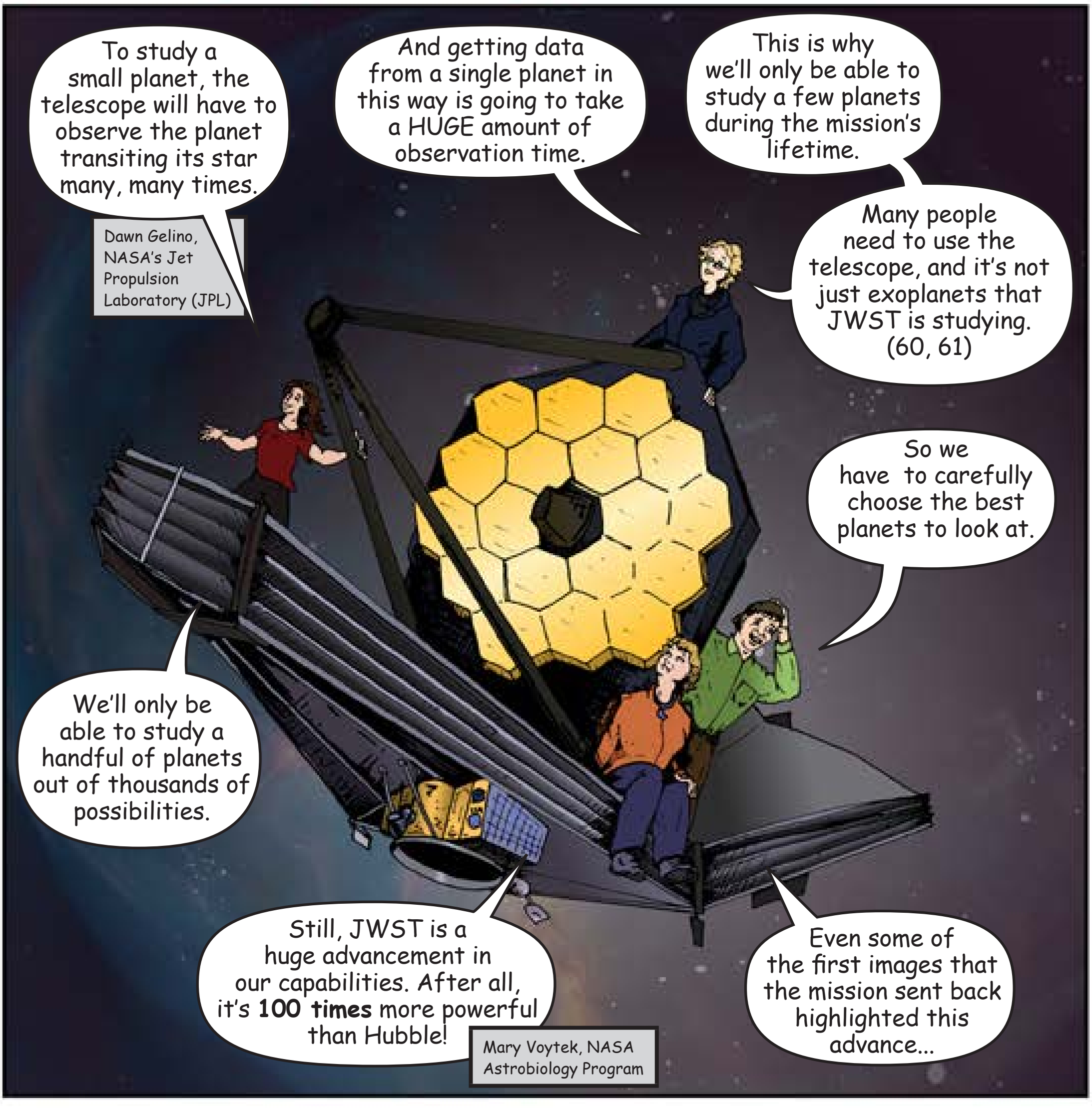

After TESS came the James Webb Space Telescope*, which launched in 2021. (54)
The mission is designed to study the early universe...
...the evolution of galaxies...
...the formation of stars and planets...
...and the potential for life on other worlds.
One exciting thing for astrobiologists is that JWST can give us a really good look at those nearby M-dwarfs.
Catarina Alves de Oliveira, European Space Agency (ESA)
* JWST, or Webb


But Webb does have limitations in terms of studying planets.
Importantly, the transmission spectra we get from Webb can only tell us about the uppermost part of the atmosphere.
And it's the lower levels of the atmosphere that interest astrobiologists most.


The lower depths are where where biosignature gases would most likely be found.
Unfortunately, starlight just doesn't penetrate deep enough into the atmospheres of these planets for JWST to pick up a signal.
EXOSPHERE
THERMOSPHERE
MESOSPHERE
STRATOSPHERE
TROPOSPHERE
But the mission quickly returned data on the upper atmospheres of giant planets...
...helping us improve our technology and techniques.

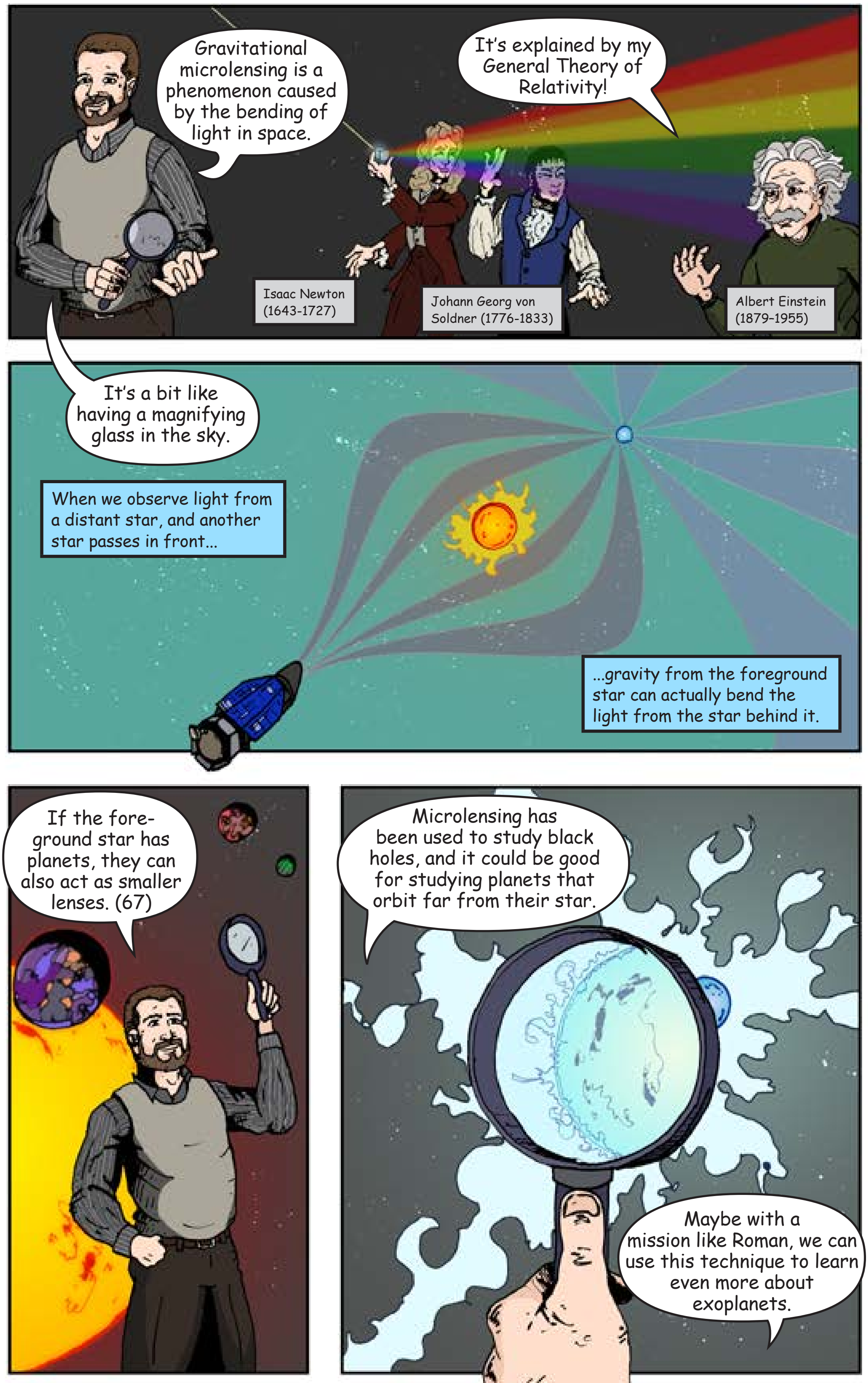

An example is what JWST has taught us about a group of rocky planets only 40 light years away.
Back in 2017, planets were found orbiting the nearby star TRAPPIST-1 using data from Spitzer and ground-based telescopes. (55)
This star is ultra-cool and only slightly larger than the planet Jupiter.
Scott Gaudi, Ohio State University
Because TRAPPIST-1 is so small and cool, the system's habitable zone is very close to the star.
Three of the seven Earth-sized planets orbit well within this habitable zone.
By studying the interactions of the planets, scientists were able to determine their masses.
It was the first time that scientists were able to infer masses for planets this small.
Three planets in the habitable zone, with sizes AND masses similar to Earth's...
...all orbiting close to their star, where it is easier for us to see them....
We were anxious to get a better look at these worlds...
And JWST gave us that chance in 2023 (56).

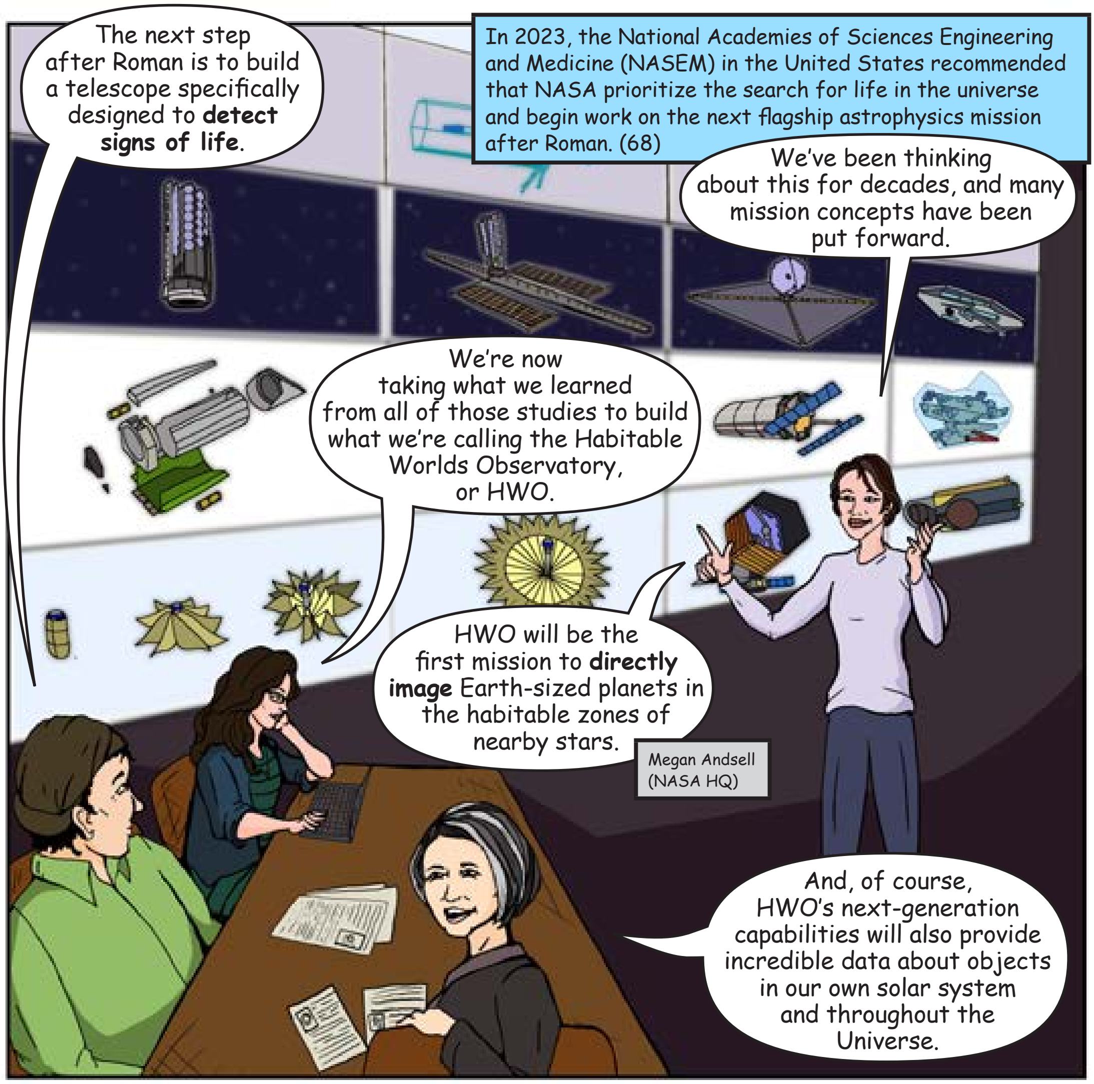

The mission was able to measure the temperature of the planet Trappist-1b based on its thermal emission. (57)
Aki Roberge, NASA GSFC
Some scientists had speculated that the planet Trappist-1c might have a thick CO2 atmosphere, but data showed that this wasn't the case. (58)
But other studies still leave hope for water vapor or oxygen. (59)
Michaël Gillon, Université de Liège

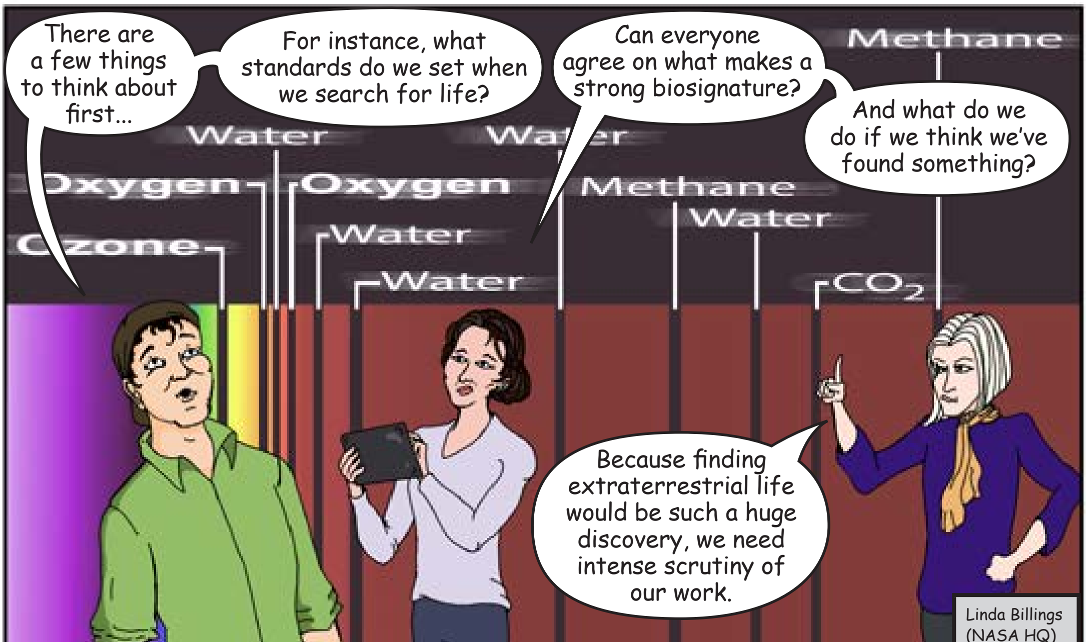

To study a small planet, the telescope will have to observe the planet transiting its star many, many times.
Dawn Gelino, NASA's Jet Propulsion Laboratory (JPL)
And getting data from a single planet in this way is going to take a HUGE amount of observation time.
This is why we'll only be able to study a few planets during the mission's lifetime.
Many people need to use the telescope, and it's not just exoplanets that JWST is studying. (60, 61)
So we have to carefully choose the best planets to look at.
We'll only be able to study a handful of planets out of thousands of possibilities.
Still, JWST is a huge advancement in our capabilities. After all, it's 100 times more powerful than Hubble!
Mary Voytek, NASA Astrobiology Program
Even some of the first images that the mission sent back highlighted this advance...

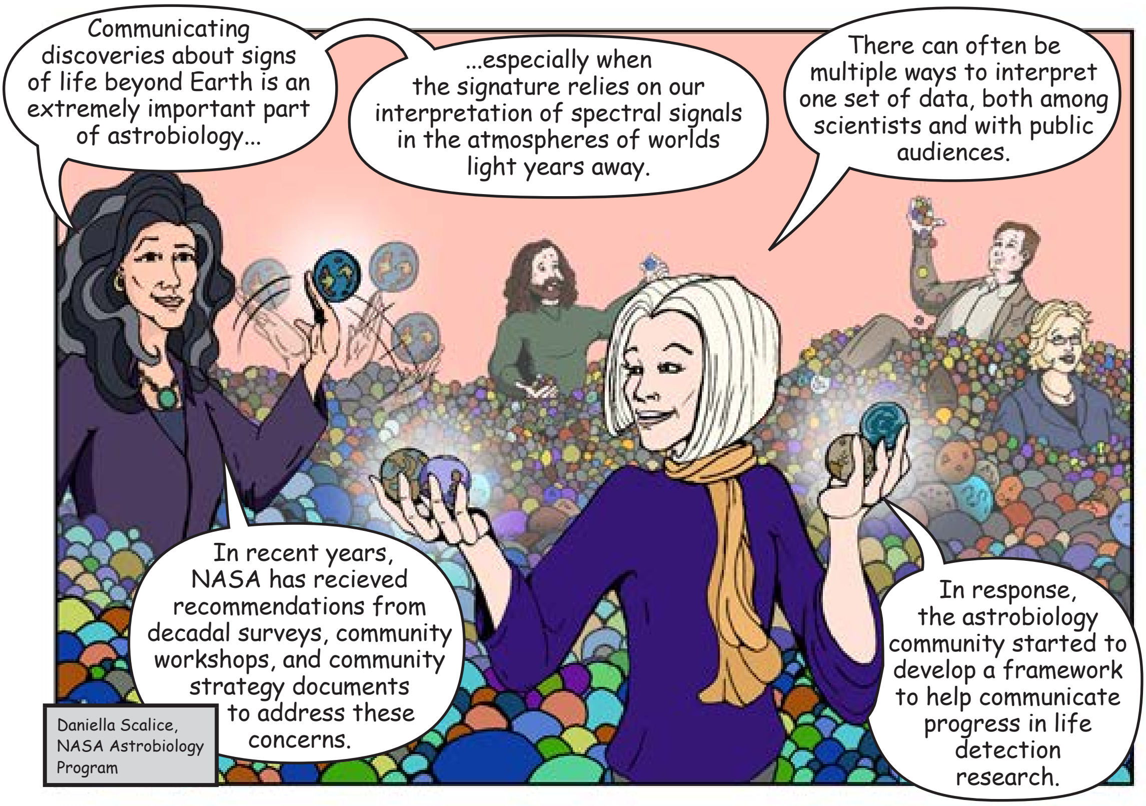

Hubble Image.
This is the edge of a nearby, young, star-forming region in the Carina Nebula.
62
Webb Image.
Called the Cosmic Cliffs, the region is actually the rim of a gigantic, gaseous cavity within the nebula, roughly 7,600 light-years away.
63
These are two images of the towering tendrils of of cosmic dust and gas in the Eagle Nebula.
Hubble Image.
64
Hubble made these features famous with the 'Pillars of Creation' image in 2018 (left). Then Webb caught a glimpse in 2022 (right).
Webb Image.
65

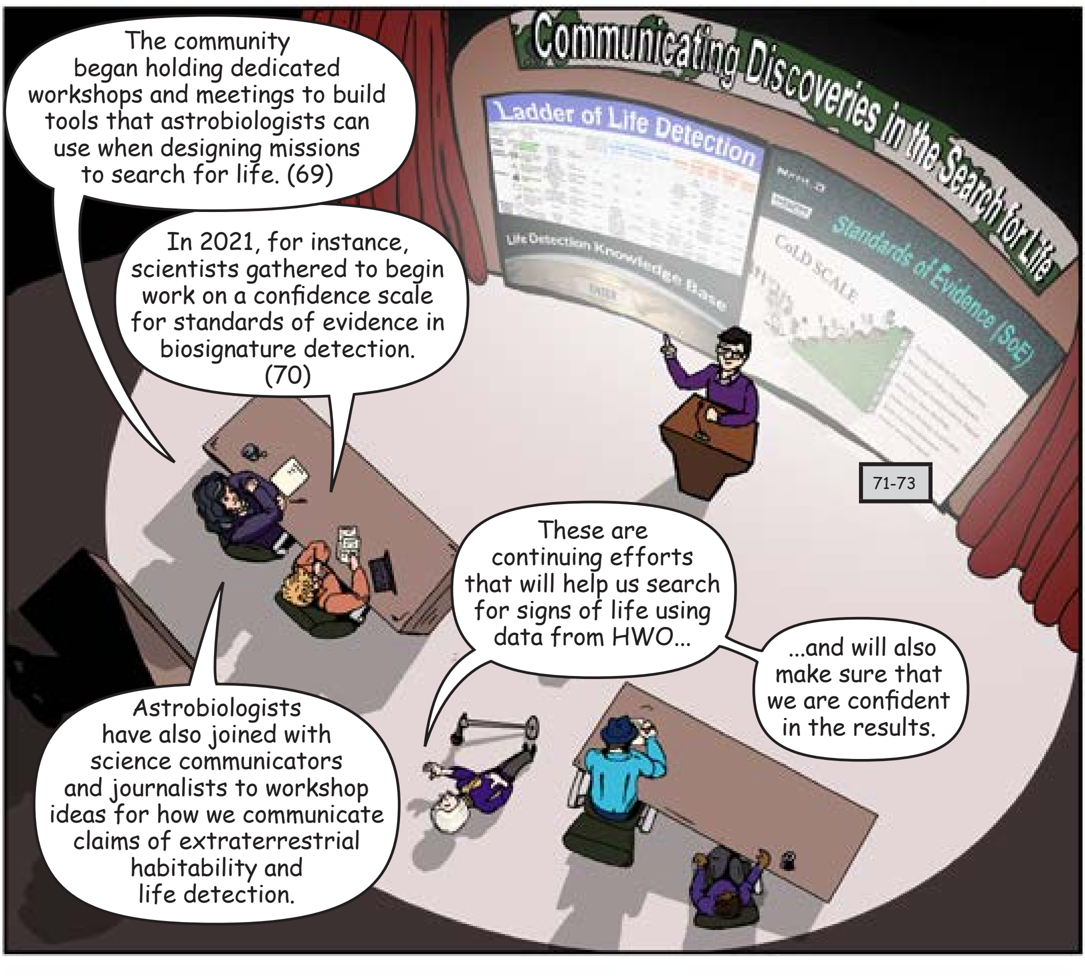

JWST is a major stepping stone.
And even more powerful telescopes are on the horizon.
Doug Hudgins, Program Scientist, NASA Exoplanet Exploration Program
In order to better characterize habitable planets...
...we want a mission that can take **direct images** of them.
Karl Stapelfeldt, Exoplanet Exploration Program Office Chief Scientist at JPL
To take a picture of a planet, we have to block the huge amount of light coming from the star it orbits.
We get 10,000,000,000 photons from a star for every ONE photon from an Earth-like planet!
Technology like starshades and coronagraphs could help.
Starshades are separate structures that can block light.
Coronagraphs are built into a telescope.
Currently, a coronograph is being built into the planned Nancy Grace Roman Space Telescope*.
* See page 7.
Roman's coronagraph is only a demonstration of the tech, but would still allow us to see planets that are almost a billion times fainter than their host star. (66)
Over time, we'll perfect the technique and study smaller and smaller planets.
And Roman's powerful main camera could also take images 100 times larger than Hubble.
It might allow scientists to use new planet-hunting techniques, like gravitational microlensing.

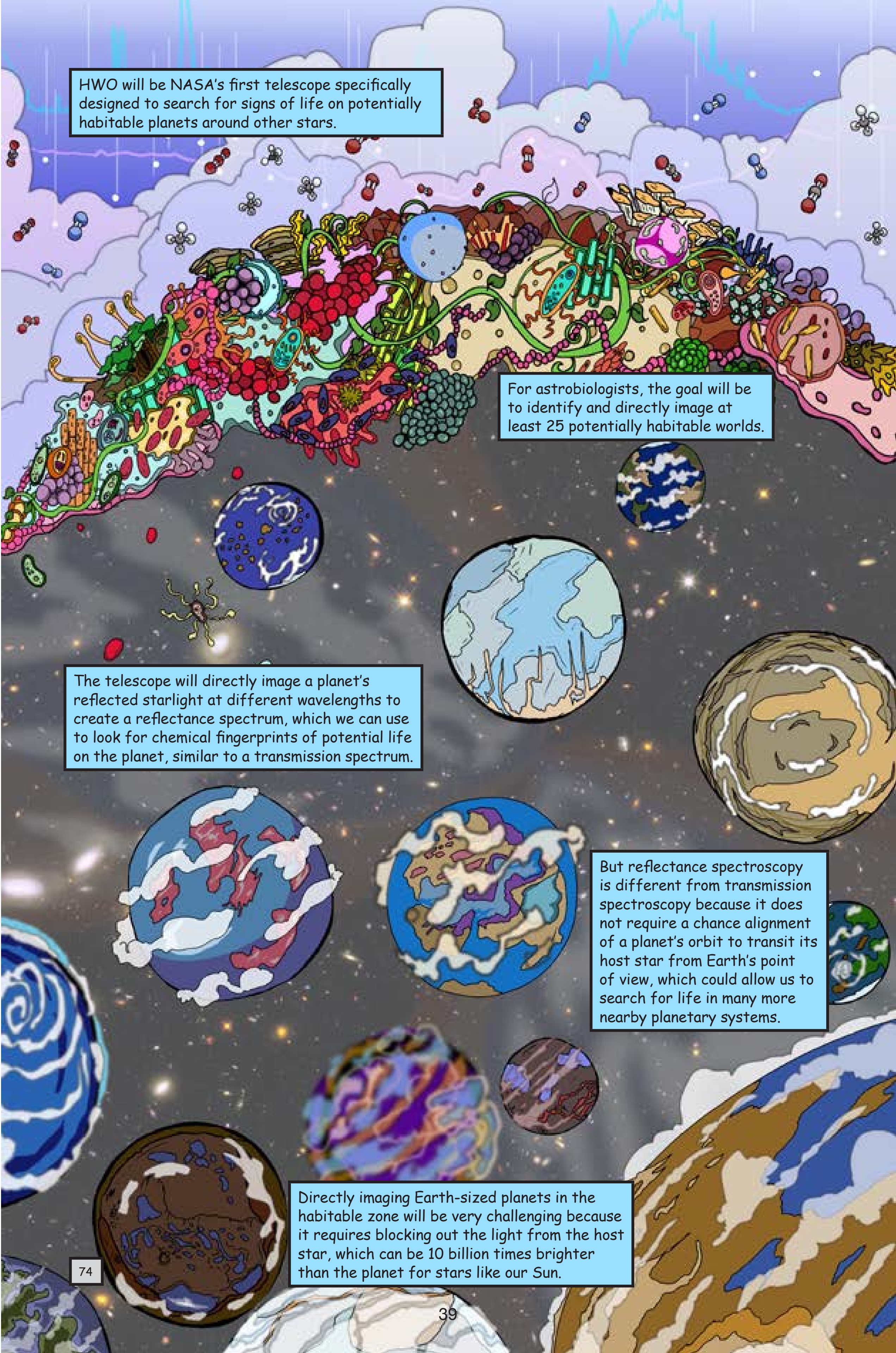

Gravitational microlensing is a phenomenon caused by the bending of light in space.
It's explained by my General Theory of Relativity!
Isaac Newton (1643-1727)
Johann Georg von Soldner (1776-1833)
Albert Einstein (1879–1955)
It's a bit like having a magnifying glass in the sky.
When we observe light from a distant star, and another star passes in front...
...gravity from the foreground star can actually bend the light from the star behind it.
If the fore-ground star has planets, they can also act as smaller lenses. (67)
Microlensing has been used to study black holes, and it could be good for studying planets that orbit far from their star.
Maybe with a mission like Roman, we can use this technique to learn even more about exoplanets.


The next step after Roman is to build a telescope specifically designed to **detect signs of life**.
In 2023, the National Academies of Sciences Engineering and Medicine (NASEM) in the United States recommended that NASA prioritize the search for life in the universe and begin work on the next flagship astrophysics mission after Roman. (68)
We've been thinking about this for decades, and many mission concepts have been put forward.
We're now taking what we learned from all of those studies to build what we're calling the Habitable Worlds Observatory, or HWO.
HWO will be the first mission to **directly image** Earth-sized planets in the habitable zones of nearby stars.
Megan Andsell (NASA HQ)
And, of course, HWO's next-generation capabilities will also provide incredible data about objects in our own solar system and throughout the Universe.


There are a few things to think about first...
For instance, what standards do we set when we search for life?
Can everyone agree on what makes a strong biosignature?
And what do we do if we think we've found something?
Methane
Water
Water
Oxygen
Oxygen
Methane
Water
Ozone
Water
Water
CO_2
Because finding extraterrestrial life would be such a huge discovery, we need intense scrutiny of our work.
Linda Billings (NASA HQ)

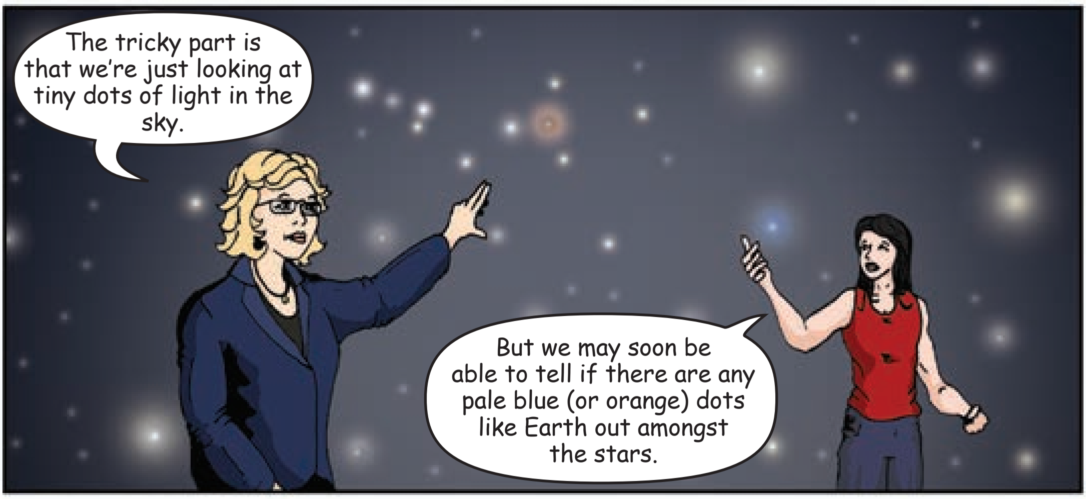

Communicating discoveries about signs of life beyond Earth is an extremely important part of astrobiology...
...especially when the signature relies on our interpretation of spectral signals in the atmospheres of worlds light years away.
There can often be multiple ways to interpret one set of data, both among scientists and with public audiences.
In recent years, NASA has recieved recommendations from decadal surveys, community workshops, and community strategy documents to address these concerns.
In response, the astrobiology community started to develop a framework to help communicate progress in life detection research.
Daniella Scalice, NASA Astrobiology Program

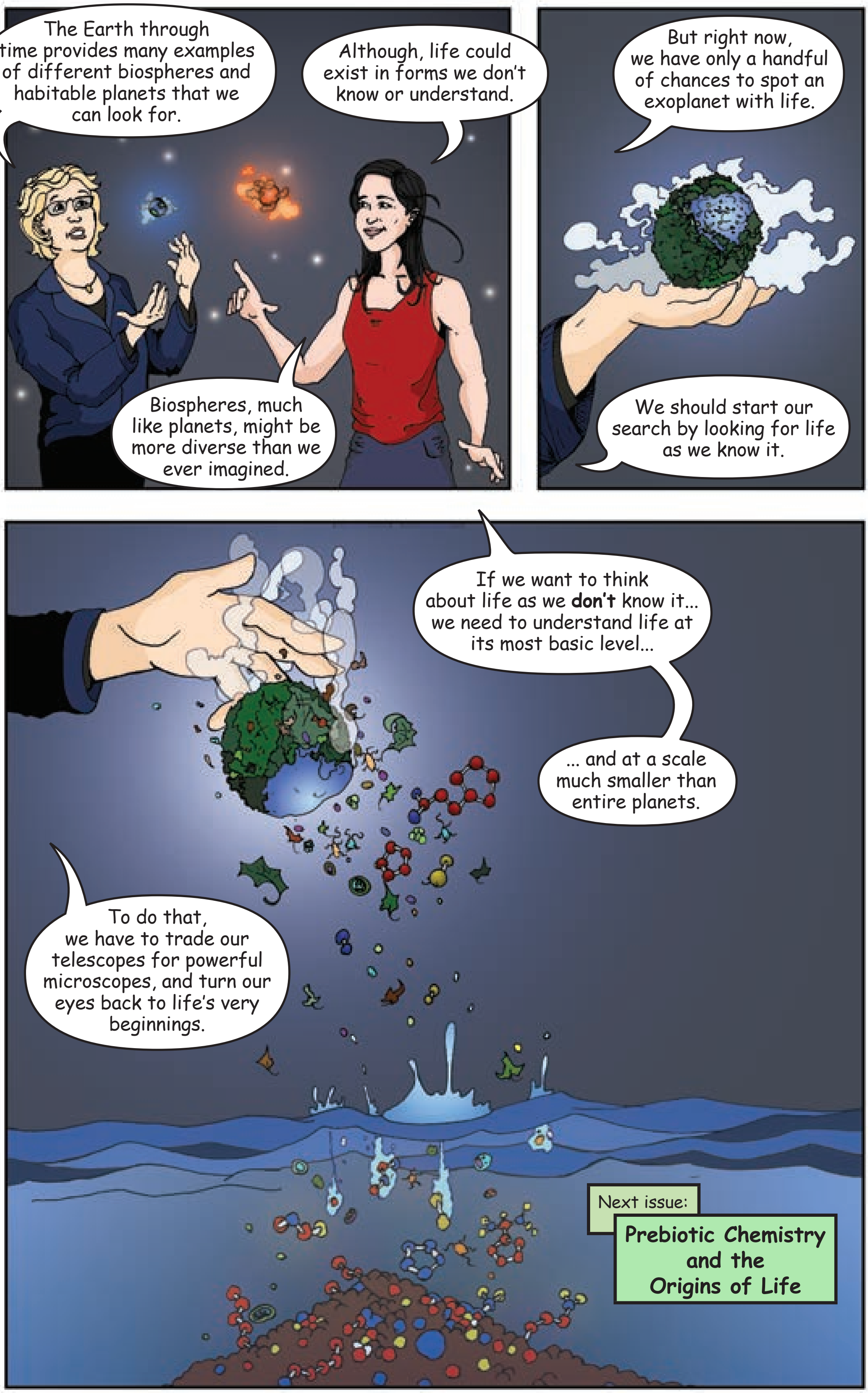

Communicating Discoveries in the Search for Life
Ladder of Life Detection
Life Detection Knowledge Base
Standards of Evidence (SoE)
CoLD SCALE
The community began holding dedicated workshops and meetings to build tools that astrobiologists can use when designing missions to search for life. (69)
In 2021, for instance, scientists gathered to begin work on a confidence scale for standards of evidence in biosignature detection. (70)
71-73
Astrobiologists have also joined with science communicators and journalists to workshop ideas for how we communicate claims of extraterrestrial habitability and life detection.
These are continuing efforts that will help us search for signs of life using data from HWO...
...and will also make sure that we are confident in the results.


HWO will be NASA's first telescope specifically designed to search for signs of life on potentially habitable planets around other stars.
For astrobiologists, the goal will be to identify and directly image at least 25 potentially habitable worlds.
The telescope will directly image a planet's reflected starlight at different wavelengths to create a reflectance spectrum, which we can use to look for chemical fingerprints of potential life on the planet, similar to a transmission spectrum.
But reflectance spectroscopy is different from transmission spectroscopy because it does not require a chance alignment of a planet's orbit to transit its host star from Earth's point of view, which could allow us to search for life in many more nearby planetary systems.
Directly imaging Earth-sized planets in the habitable zone will be very challenging because it requires blocking out the light from the host star, which can be 10 billion times brighter than the planet for stars like our Sun.
74


Cancelling starlight will make it possible to directly characterize exoplanets.
We aren't finished designing HWO yet, but it will be the most powerful astrophysics telescope NASA has ever launched.
After decades of planning, it's time to get it done!
Bertrand Mennesson, NASA JPL
Breann Sitarski, NASA GSFC
Lee Feinberg, NASA GSFC


We could be so close to characterizing some truly habitable planets...
... or maybe even finding an **inhabited** one.


The tricky part is that we're just looking at tiny dots of light in the sky.
But we may soon be able to tell if there are any pale blue (or orange) dots like Earth out amongst the stars.


The Earth through time provides many examples of different biospheres and habitable planets that we can look for.
Although, life could exist in forms we don't know or understand.
Biospheres, much like planets, might be more diverse than we ever imagined.
But right now, we have only a handful of chances to spot an exoplanet with life.
We should start our search by looking for life as we know it.
If we want to think about life as we **don't** know it... we need to understand life at its most basic level...
... and at a scale much smaller than entire planets.
To do that, we have to trade our telescopes for powerful microscopes, and turn our eyes back to life's very beginnings.
Next issue:
Prebiotic Chemistry and the Origins of Life

Astrobiology

A History of Exobiology and Astrobiology at NASA

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