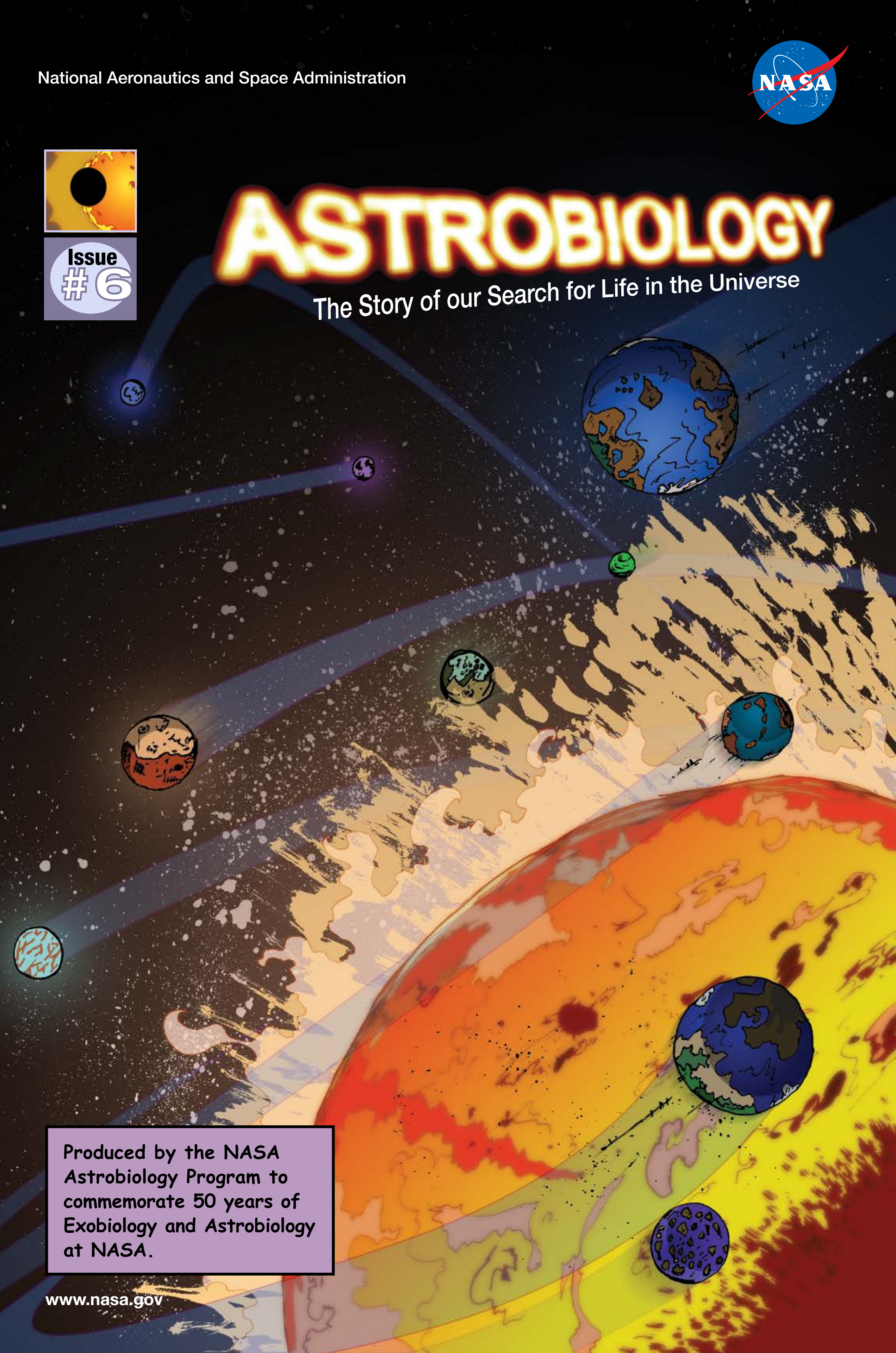
National Aeronautics and Space Administration

ASTROBIOLOGY

The Story of our Search for Life in the Universe

Issue #6



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 only 50 years old, 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

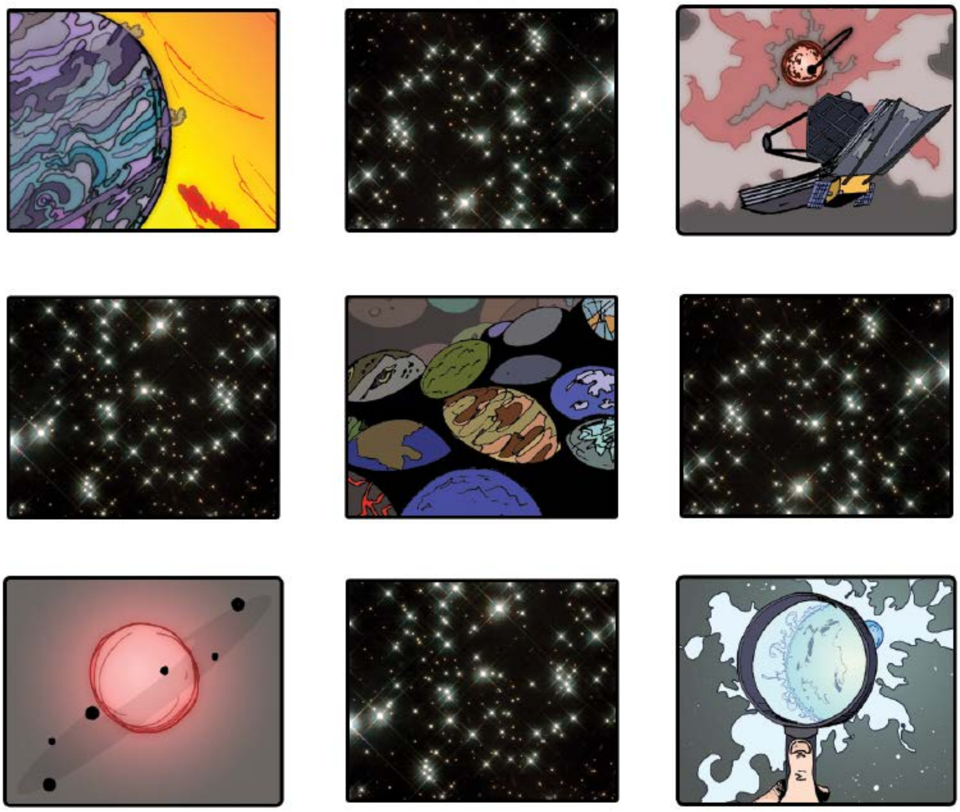
Editor

Linda Billings

Layout

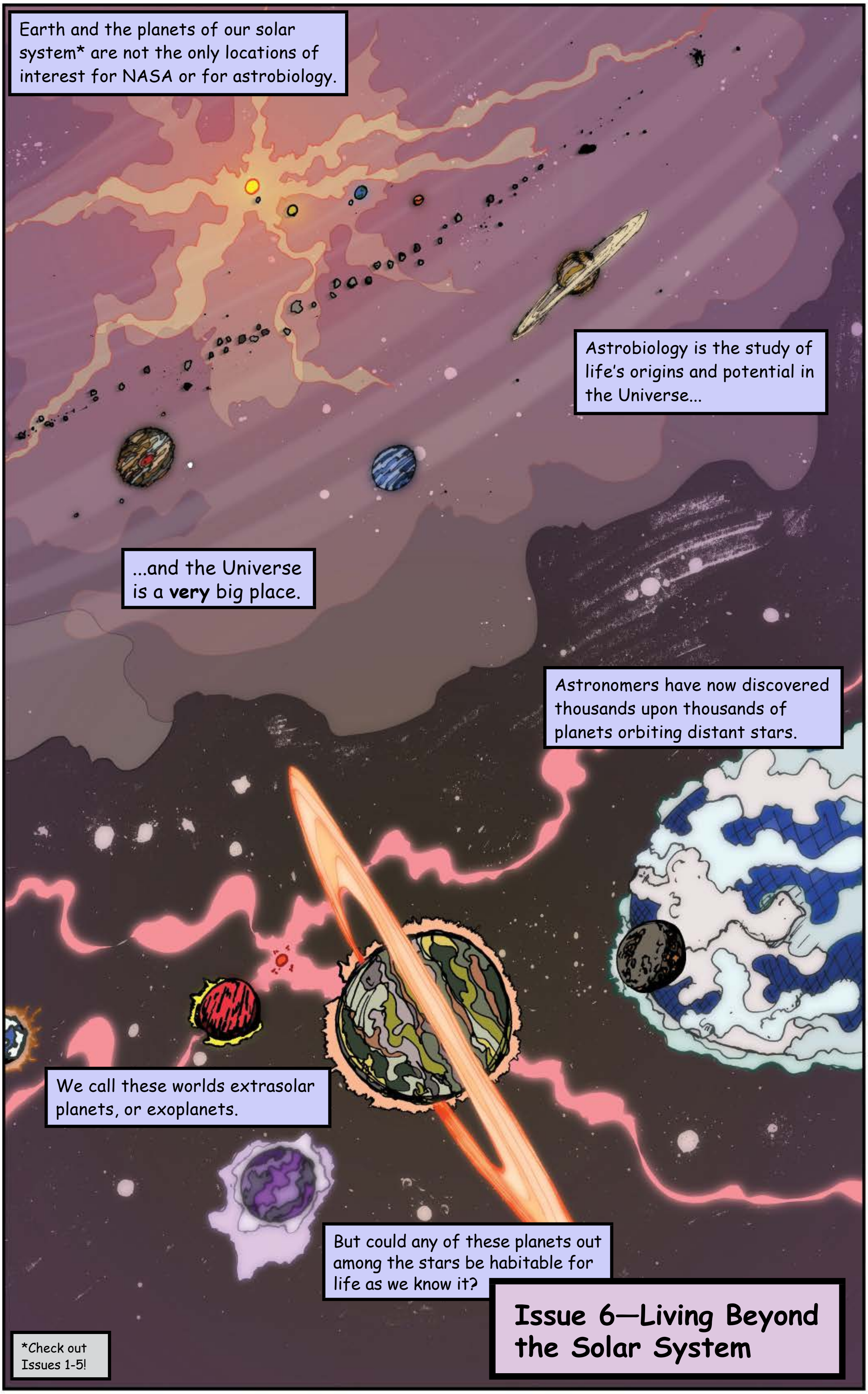
Aaron L. Gronstal
Jenny Mottar

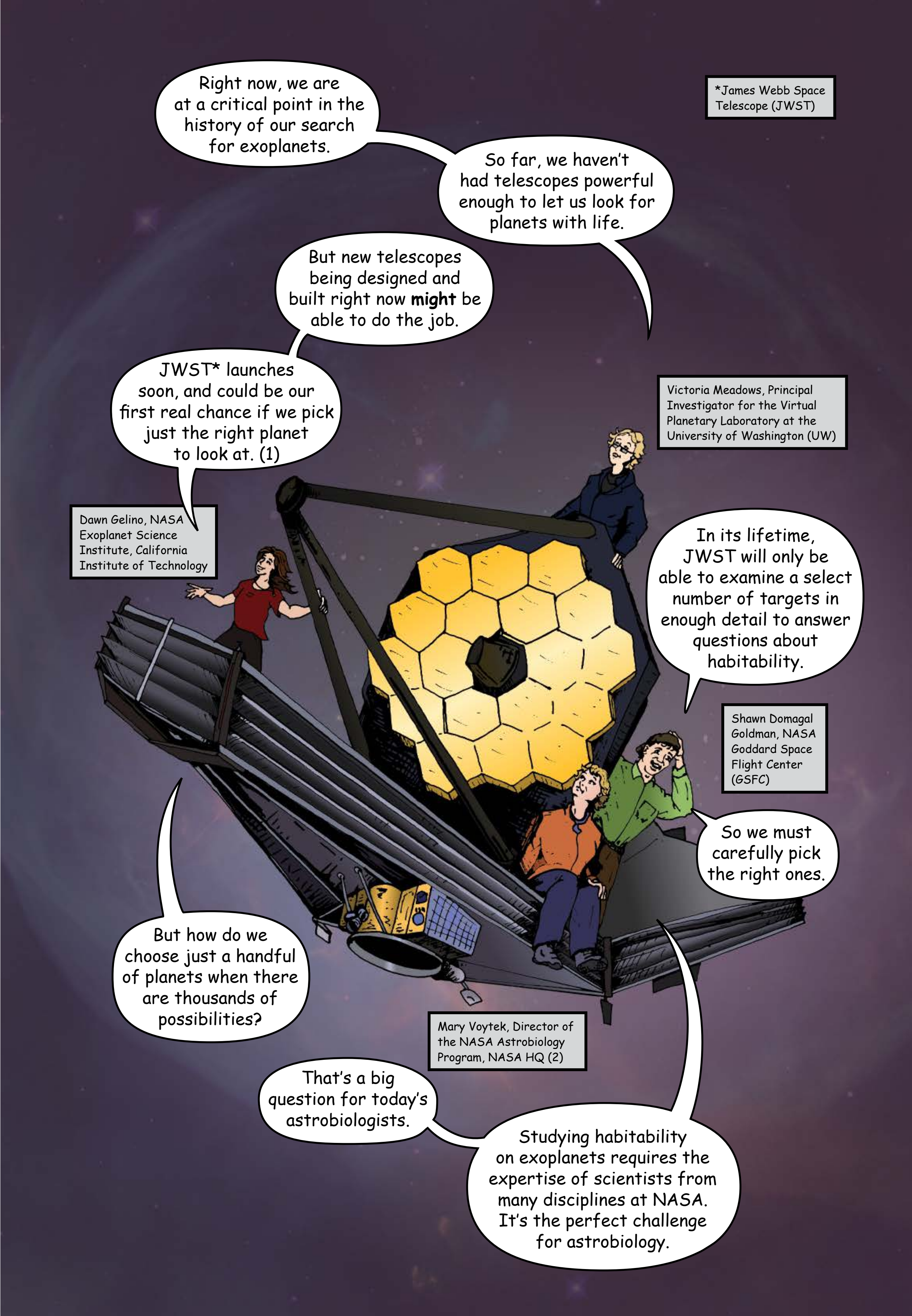
Issue #6—Living Beyond the Solar System



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. 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 sixth 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.

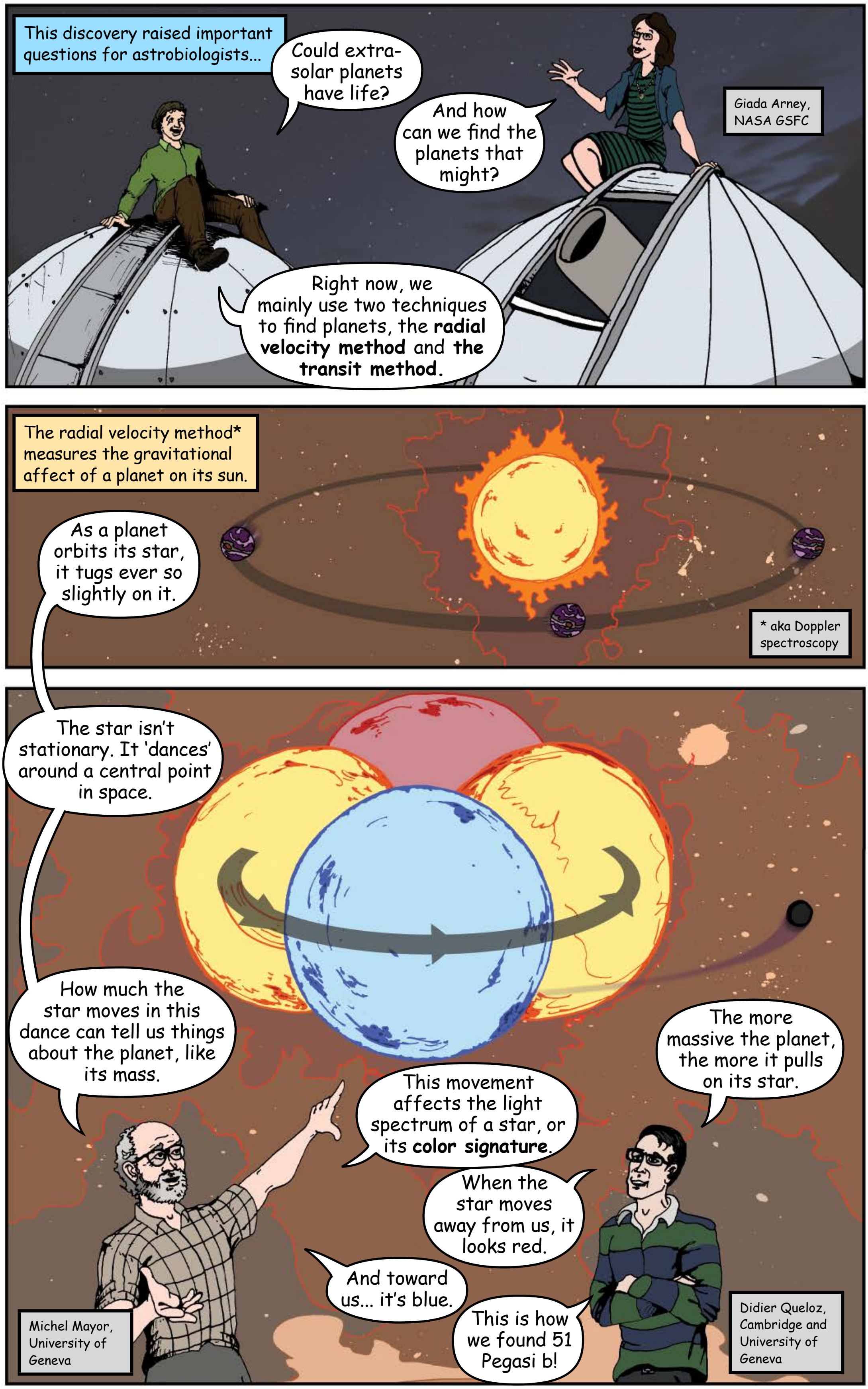
-Linda Billings, Editor

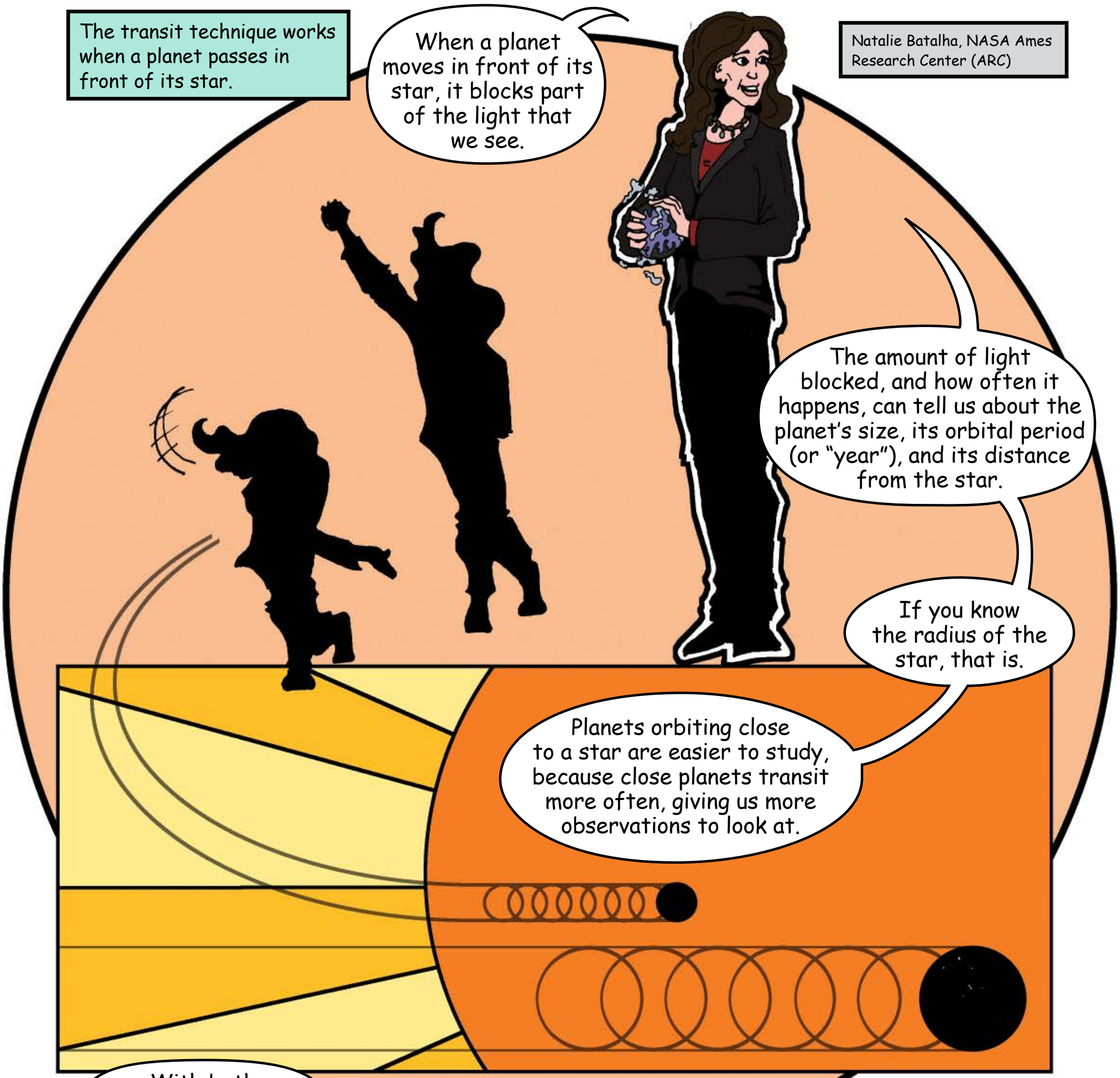

Earth and the planets of our solar system* are not the only locations of interest for NASA or for astrobiology.
Astrobiology is the study of life's origins and potential in the Universe...
...and the Universe is a **very** big place.
Astronomers have now discovered thousands upon thousands of planets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

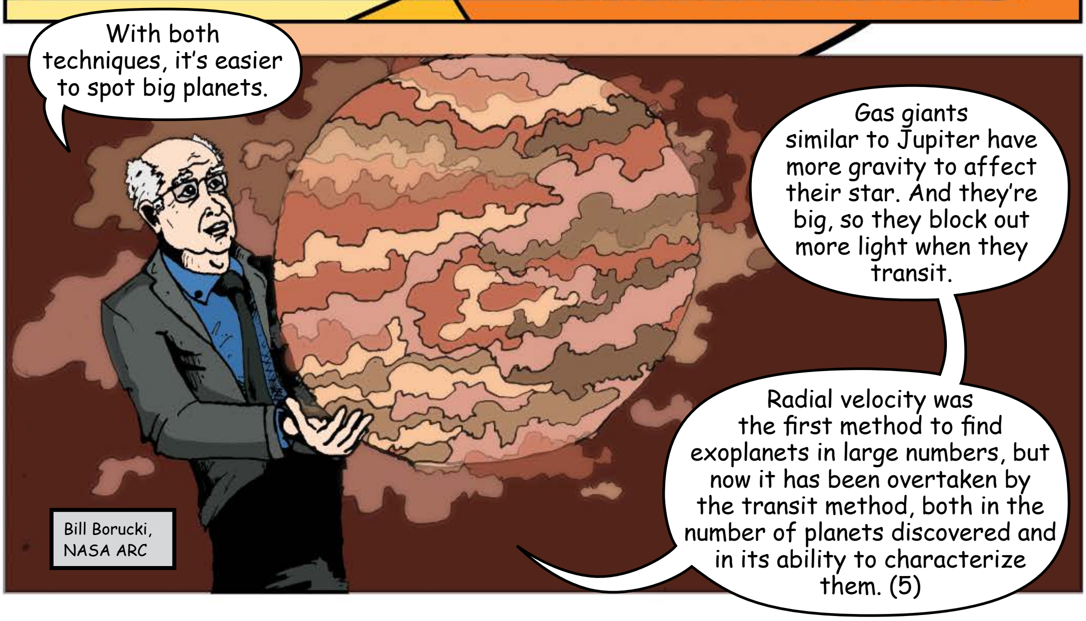


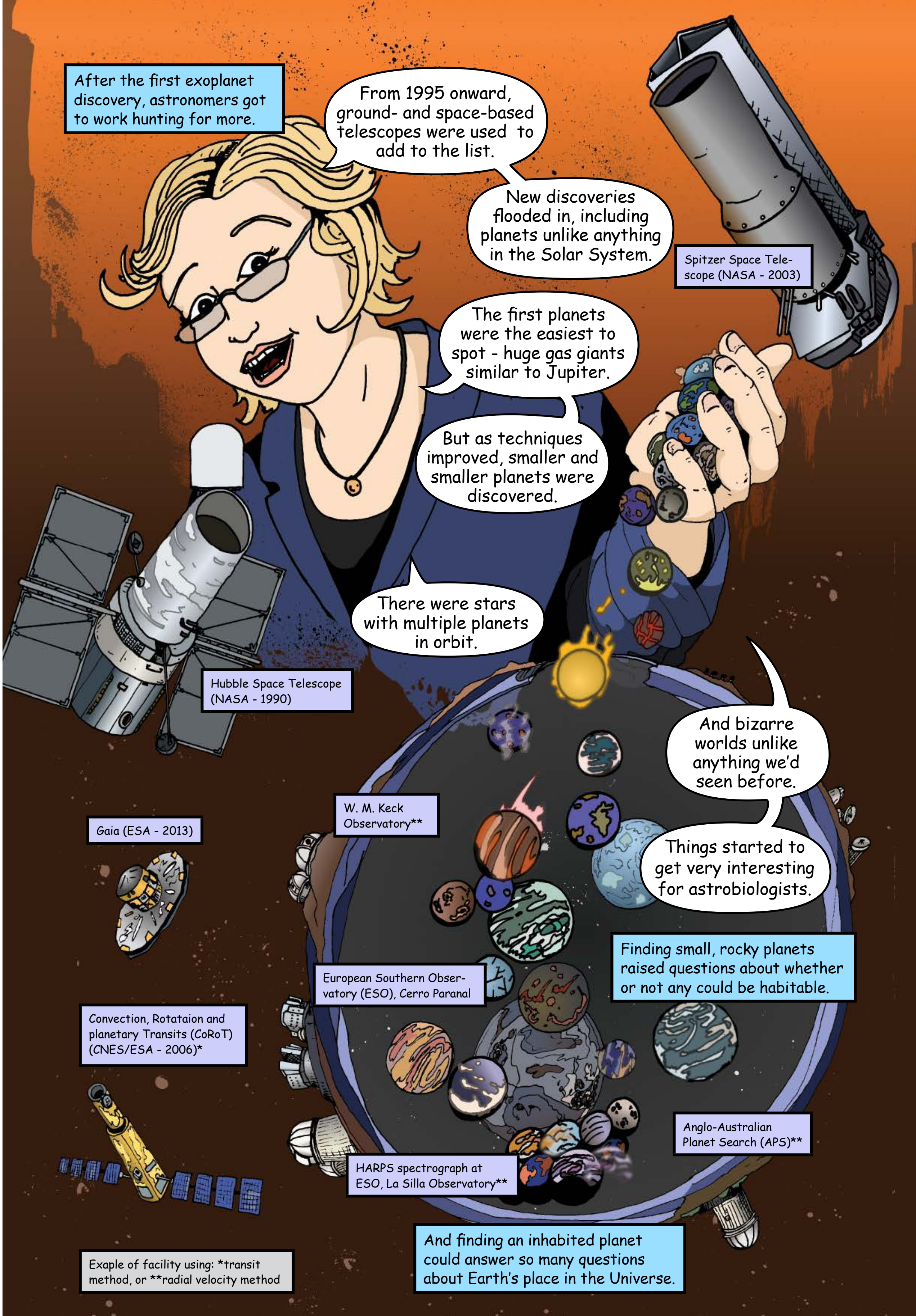
Right now, we are at a critical point in the history of our search for exoplanets.
So far, we haven't had telescopes powerful enough to let us look for planets with life.
But new telescopes being designed and built right now **might** be able to do the job.
JWST* launches soon, and could be our first real chance if we pick just the right planet to look at. (1)
*James Webb Space Telescope (JWST)
Victoria Meadows, Principal Investigator for the Virtual Planetary Laboratory at the University of Washington (UW)
Dawn Gelino, NASA Exoplanet Science Institute, California Institute of Technology
In its lifetime, JWST will only be able to examine a select number of targets in enough detail to answer questions about habitability.
Shawn Domagal Goldman, NASA Goddard Space Flight Center (GSFC)
So we must carefully pick the right ones.
But how do we choose just a handful of planets when there are thousands of possibilities?
Mary Voytek, Director of the NASA Astrobiology Program, NASA HQ (2)
That's a big question for today's astrobiologists.
Studying habitability on exoplanets requires the expertise of scientists from many disciplines at NASA. It's the perfect challenge for astrobiology.

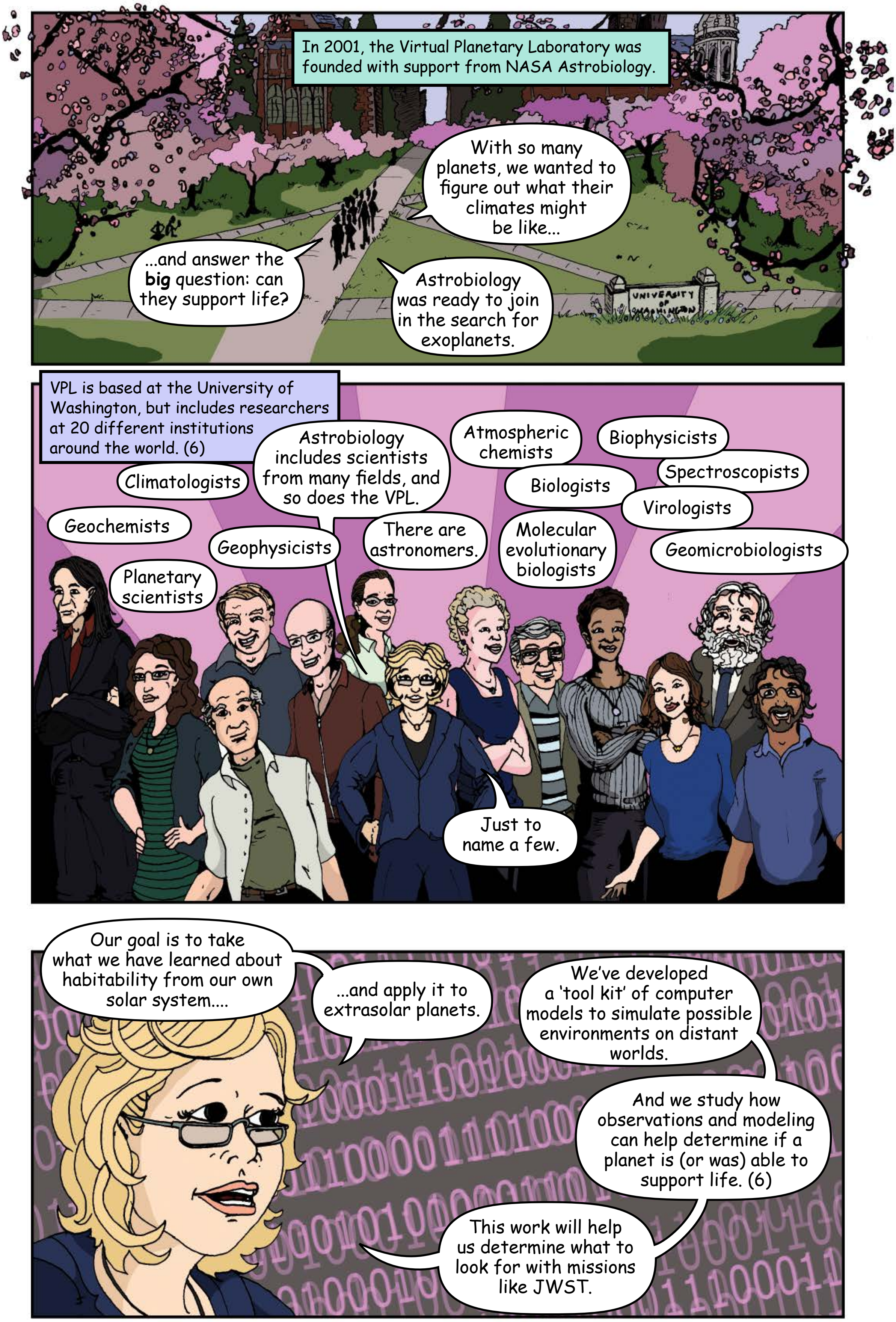

Before NASA even existed, humankind dreamt of other worlds out among the stars.*
For centuries, scientists and philosophers argued about the possibility of extrasolar planets.
I believe in a 'plurality of worlds.'
There are countless Earths rotating around their suns in exactly the same way as the planets of our system.
*see Issue #1
Giordano Bruno, 1548-1600. (3)
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.
Wait, those clouds of light are galaxies!
Edwin Hubble, 1920s.
Whoa...
...that is a **lot** of stars.
In 1995, astronomers finally found an extrasolar planet.
Mon dieu...
A giant planet rapidly orbits the star 51 Pegasi! (4)
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...
Could extra-solar planets have life?
And how can we find the planets that might?
Giada Arney, NASA GSFC
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, Cambridge and University of Geneva

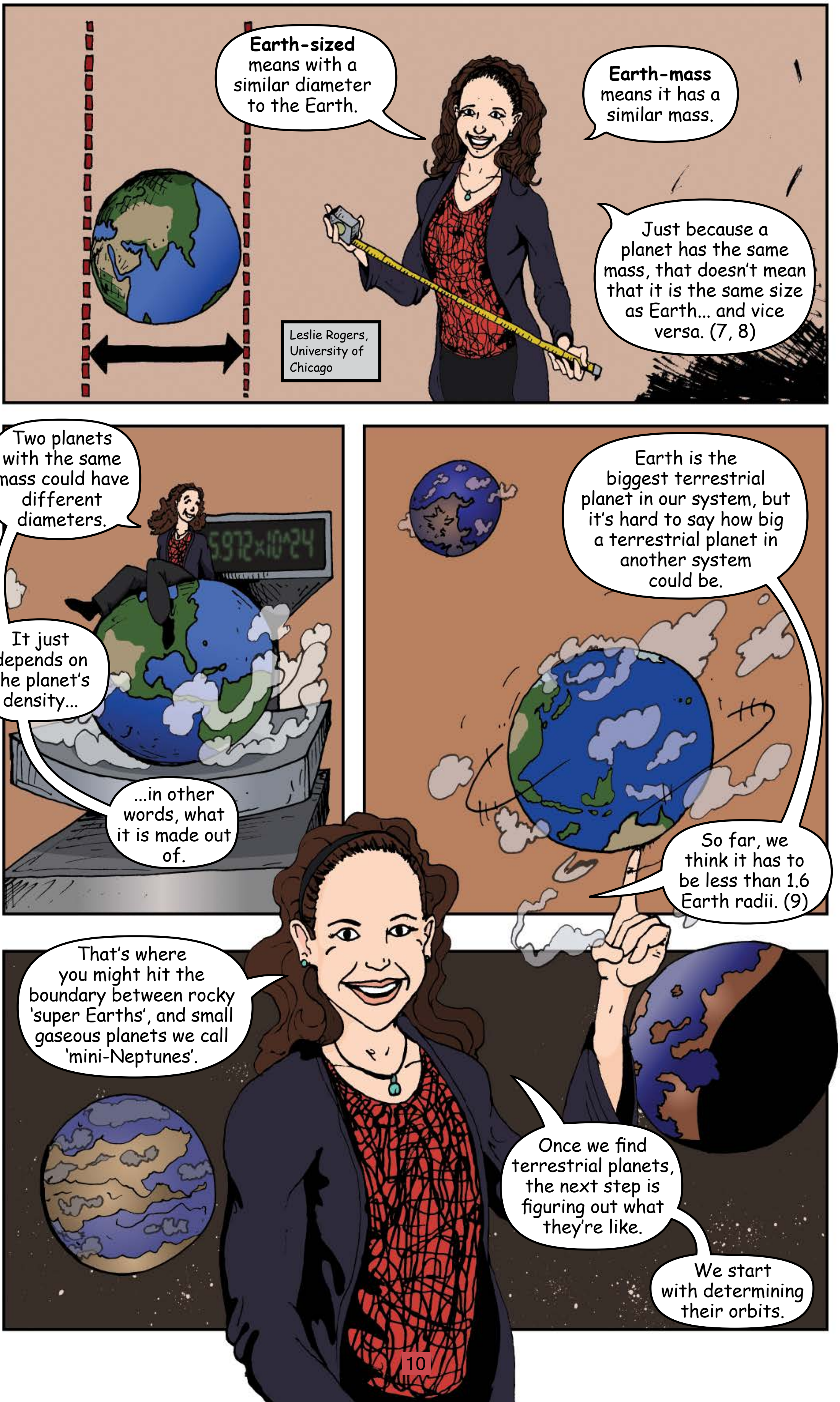

The transit technique works when a planet passes in front of its star.
When a planet moves in front of its star, it blocks part of the light that we see.
Natalie Batalha, NASA Ames Research Center (ARC)
The amount of light blocked, and how often it happens, can tell us about the planet's size, its orbital 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.

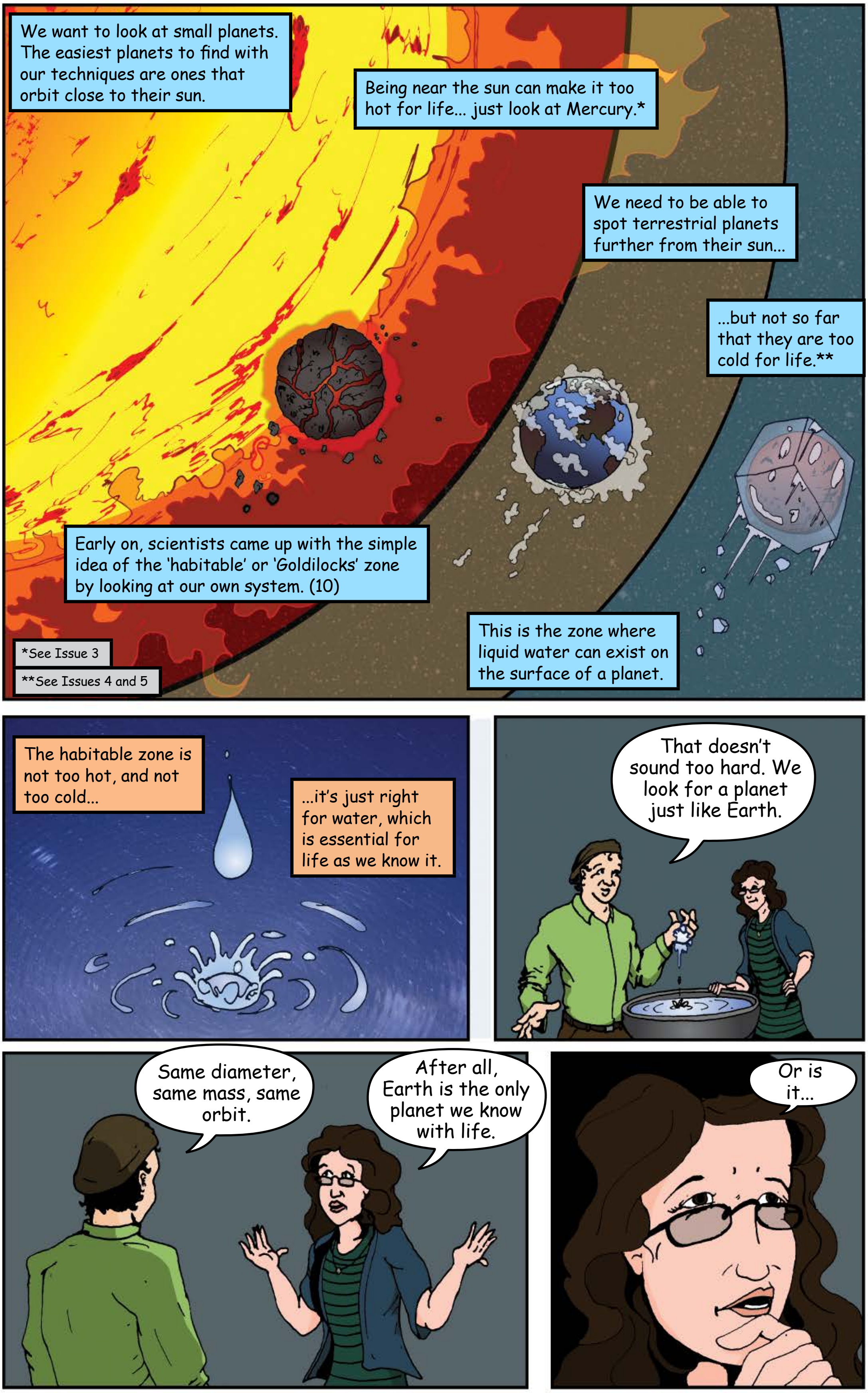

With both techniques, it's easier to spot big planets.
Gas giants similar to Jupiter have more gravity to affect their star. And they're big, so they block out more light when they transit.
Radial velocity was the first method to find exoplanets in large numbers, but now it has been overtaken by the transit method, both in the number of planets discovered and in its ability to characterize them. (5)
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.
New discoveries flooded in, including planets unlike anything in the Solar System.
Spitzer Space Tele-scope (NASA - 2003)
The first planets were the easiest to spot - huge gas giants similar to Jupiter.
But as techniques improved, smaller and smaller planets were discovered.
There were stars with multiple planets in orbit.
Hubble Space Telescope (NASA - 1990)
And bizarre worlds unlike anything we'd seen before.
Things started to get very interesting for astrobiologists.
Gaia (ESA - 2013)
W. M. Keck Observatory**
Finding small, rocky planets raised questions about whether or not any could be habitable.
European Southern Obser-vatory (ESO), Cerro Paranal
Convection, Rotataion and planetary Transits (CoRoT) (CNES/ESA - 2006)*
Anglo-Australian Planet Search (APS)**
HARPS spectrograph at ESO, La Silla Observatory**
And finding an inhabited planet could answer so many questions about Earth's place in the Universe.
Exaple of facility using: *transit method, or **radial velocity method


In 2001, the Virtual Planetary Laboratory was founded with support from NASA Astrobiology.
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 includes researchers at 20 different institutions around the world. (6)
Astrobiology includes scientists from many fields, and so does the VPL.
There are astronomers.
Climatologists
Geochemists
Geophysicists
Planetary scientists
Atmospheric chemists
Biophysicists
Biologists
Spectroscopists
Virologists
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. (6)
This work will help us determine what to look for with missions like JWST.

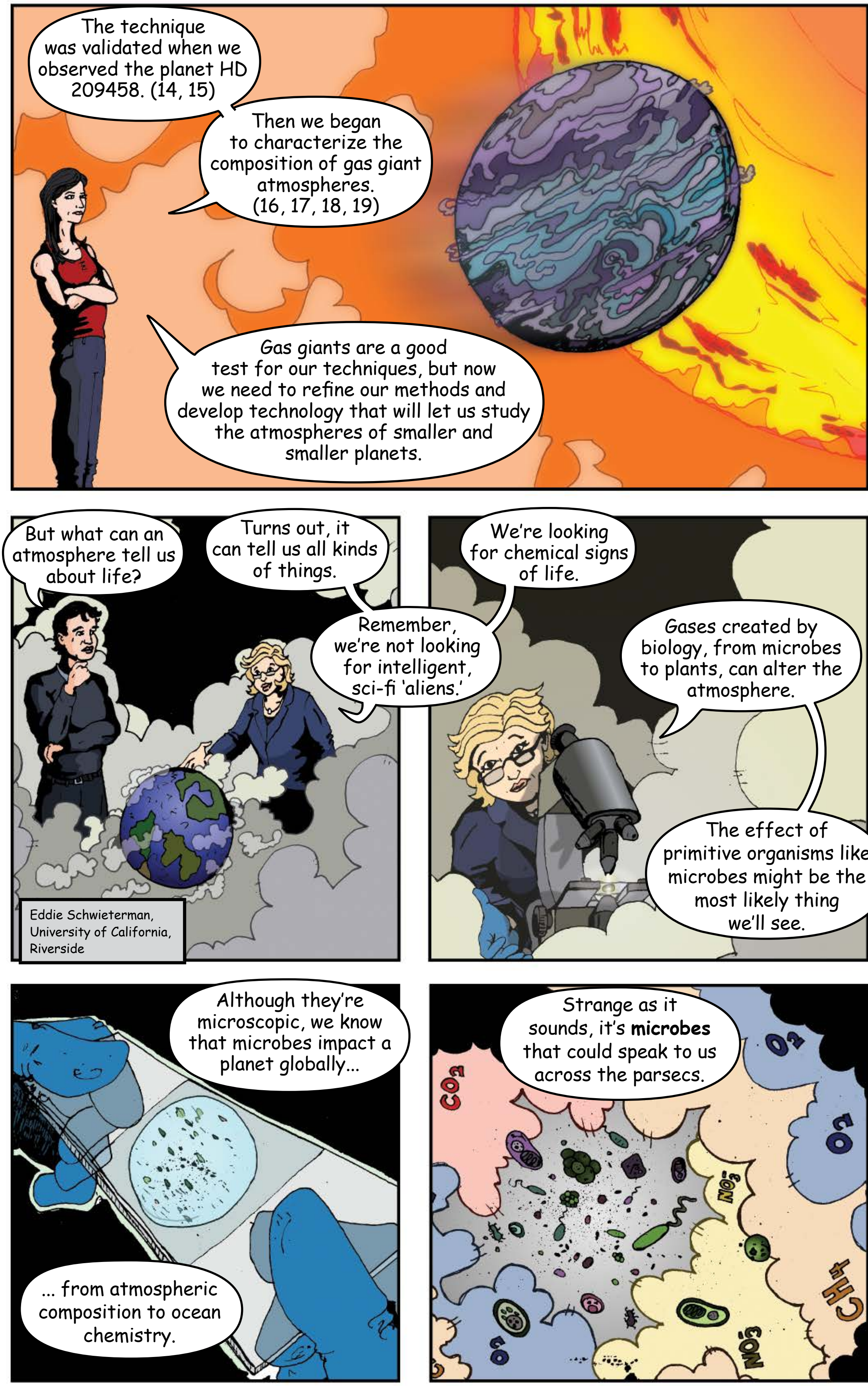

Understanding habitable planets starts with Earth.
Analog environments on Earth help us study life's potential in the Solar System*.
* See Issue 5
But Earth, the **entire** planet, is like one giant analog for habitable worlds.
Earth science helps us predict what our telescopes might see in other planetary 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**.
Bodies like the dwarf planet Pluto aren't terrestrial because they have so much ice and frozen material.
Mercury
Venus
Earth
Mars
**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, that doesn't mean that it is the same size as Earth... and vice versa. (7, 8)
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. (9)
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.

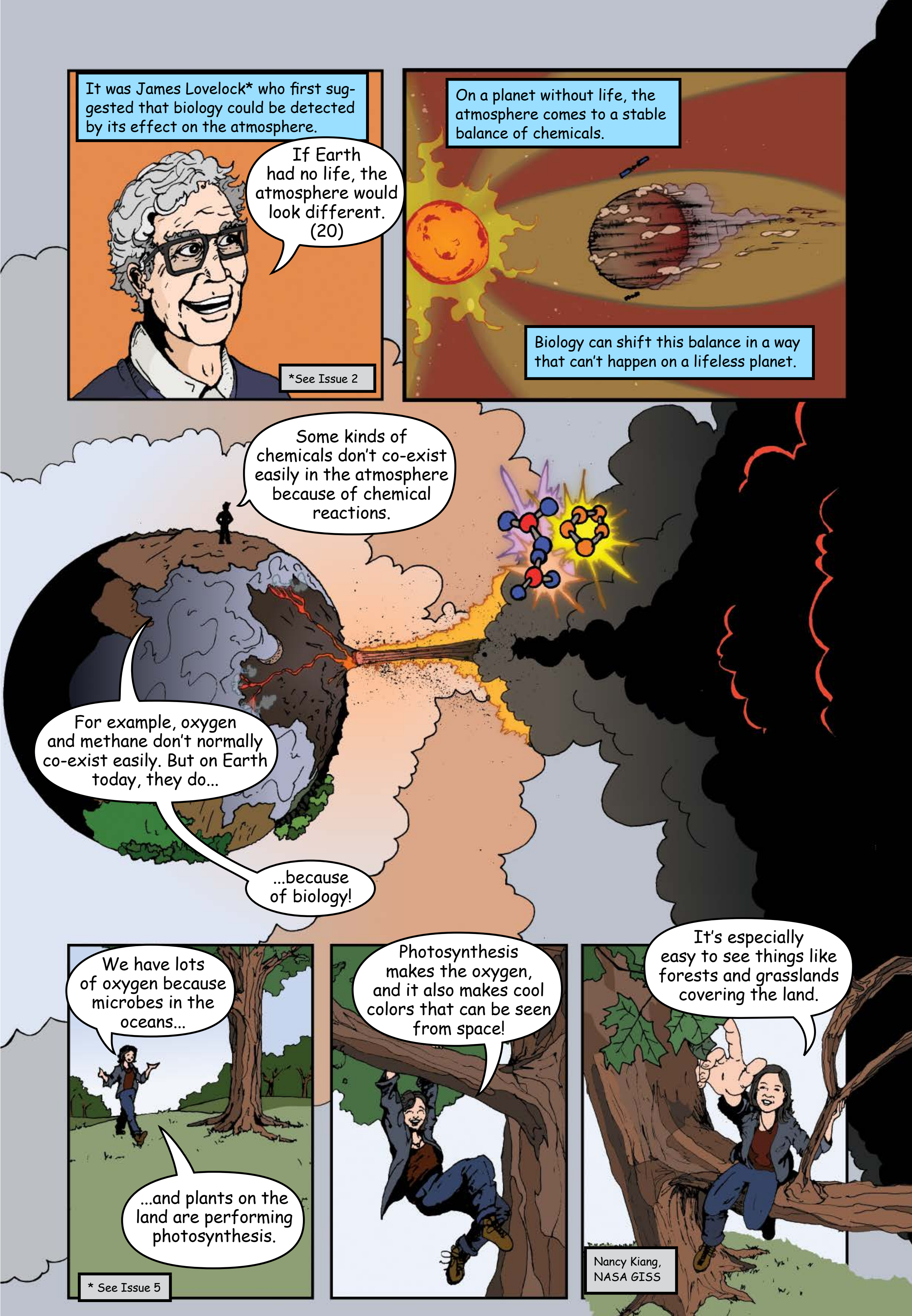

We want to look at small planets. The easiest planets to find with our techniques are ones that orbit close to their sun.
Being near the sun can make it too hot for life... just look at Mercury.*
We need to be able to spot terrestrial planets further from their sun...
...but not so far that they are 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. (10)
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 for water, which is essential for life as we know it.
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...

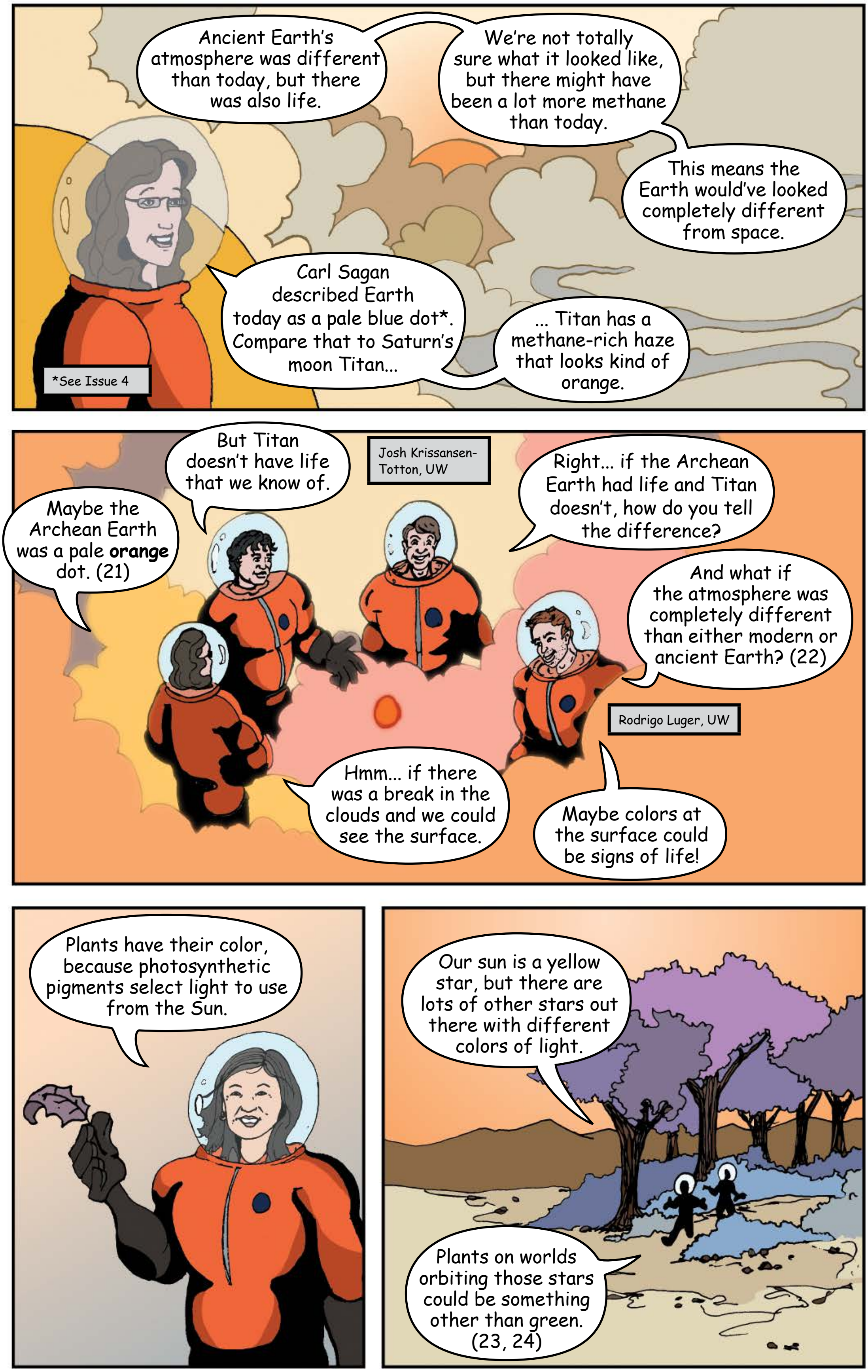

In some ways, Earth isn't the only analog we have for an inhabited world.
Maybe Earth-like exoplanets don't have to look like the Earth we know **today**.
PFFFT
Remember, we must understand the Earth **through time**.
Life has been on Earth for billions of years and, long ago, the planet looked a lot 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! (11)

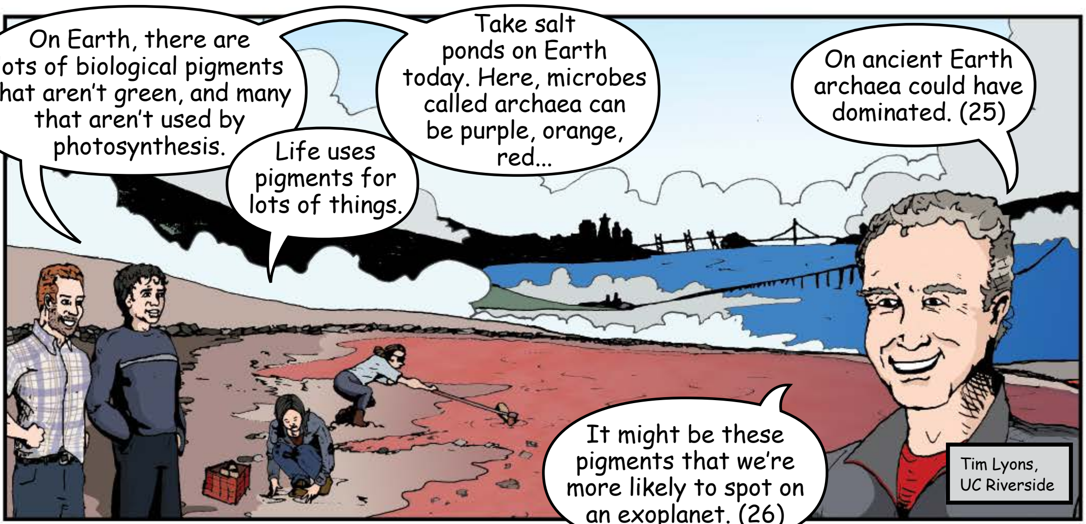

We just need to find the right planet to study, and put these ideas to the test!
That's a big challenge. Exo-planets are so **far away**.
But we can still study the planet, even though we can't see it.
Drake Deming, University of Maryland at College Park
What do you mean by that?
When a planet passes 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.
It's tough, but our techniques are getting better and better.
Ignas Snellen, Leiden University (12)
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. (13)

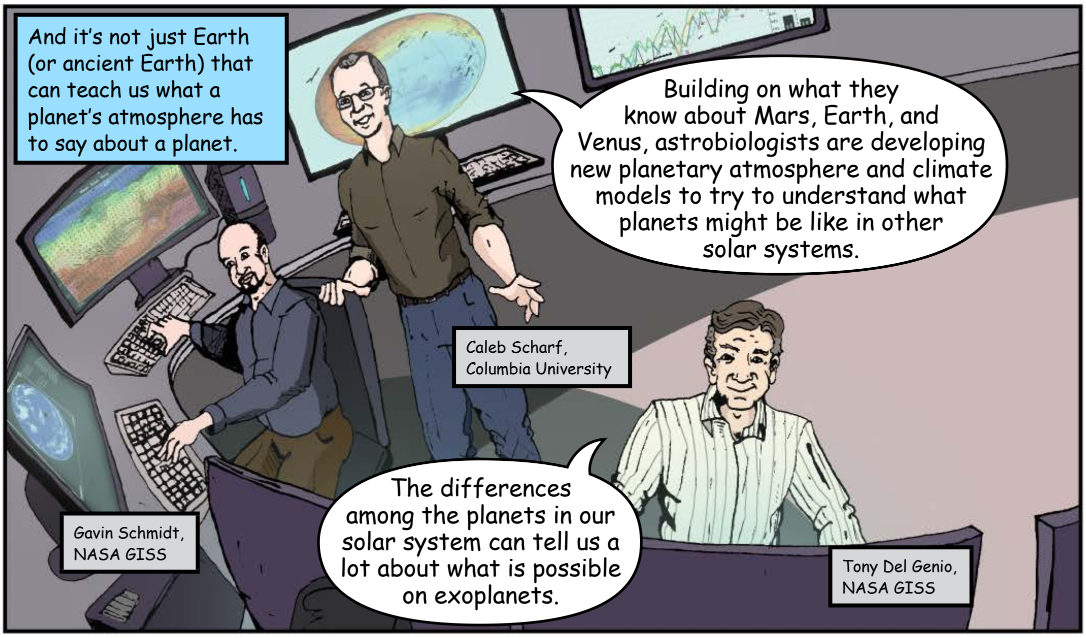


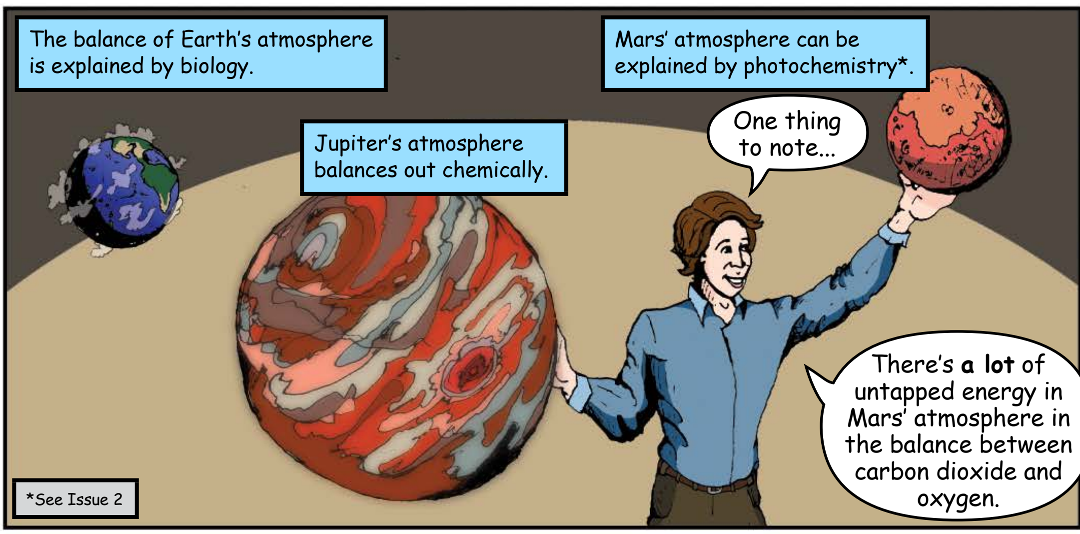
The technique was validated when we observed the planet HD 209458. (14, 15)
Then we began to characterize the composition of gas giant atmospheres. (16, 17, 18, 19)
Gas giants are a good test for our techniques, but now we need to refine our methods and develop technology that will let us study the atmospheres of smaller and smaller planets.
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
We're looking for chemical signs of life.
Gases created by biology, from microbes to plants, 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 across the parsecs.
CO2
O2
O2
NO3
CH4
O2
NO3

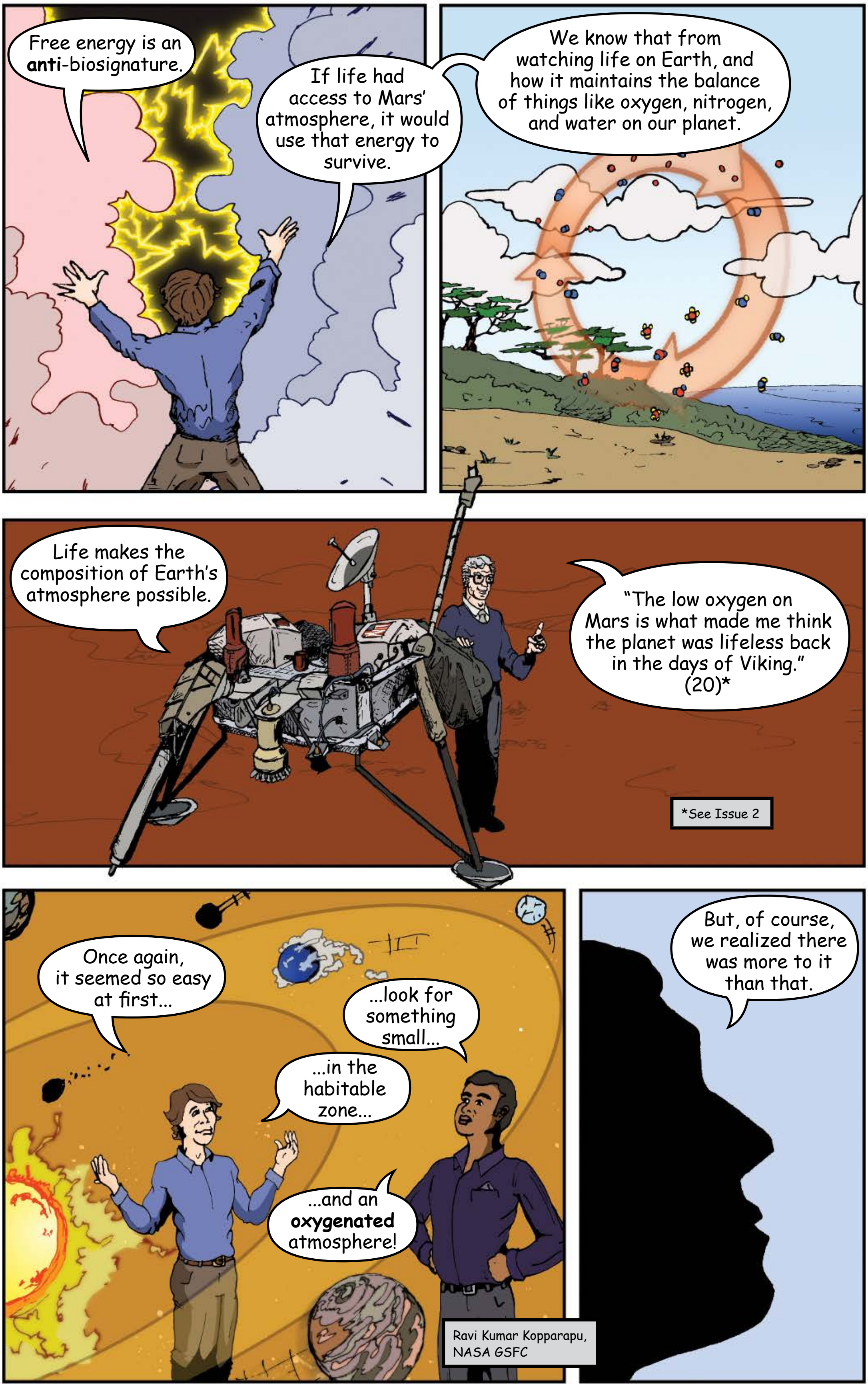

It was James Lovelock* who first suggested that biology could be detected by its effect on the atmosphere.
If Earth had no life, the atmosphere would look different. (20)
*See Issue 2
On a planet without life, the atmosphere comes to a stable balance of chemicals.
Biology can shift this balance in a 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.
* See Issue 5
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.
Nancy Kiang, NASA GISS


Ancient Earth's atmosphere was different than today, but there was also life.
We're not totally sure what it looked 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. (21)
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? (22)
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. (23, 24)

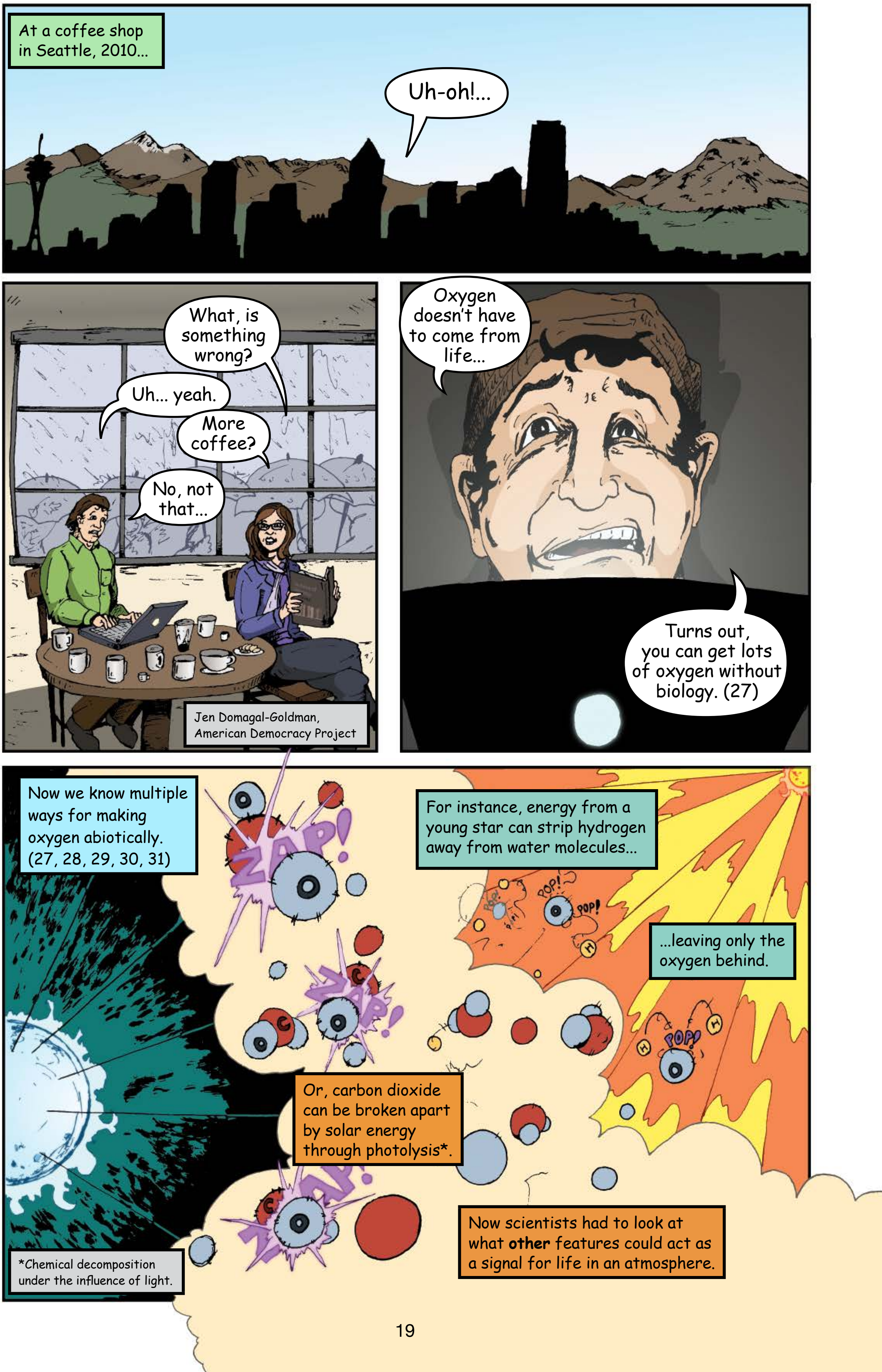

On Earth, there are lots of biological pigments that aren't green, and many that aren't used by photosynthesis.
Life uses pigments for lots of things.
Take salt ponds on Earth today. Here, microbes called archaea can be purple, orange, red...
On ancient Earth archaea could have dominated. (25)
It might be these pigments that we're more likely to spot on an exoplanet. (26)
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, Columbia University
Gavin Schmidt, NASA GISS
The differences among the planets in our solar system can tell us a lot about what is possible on exoplanets.
Tony Del Genio, NASA GISS


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.
*See Issue 2

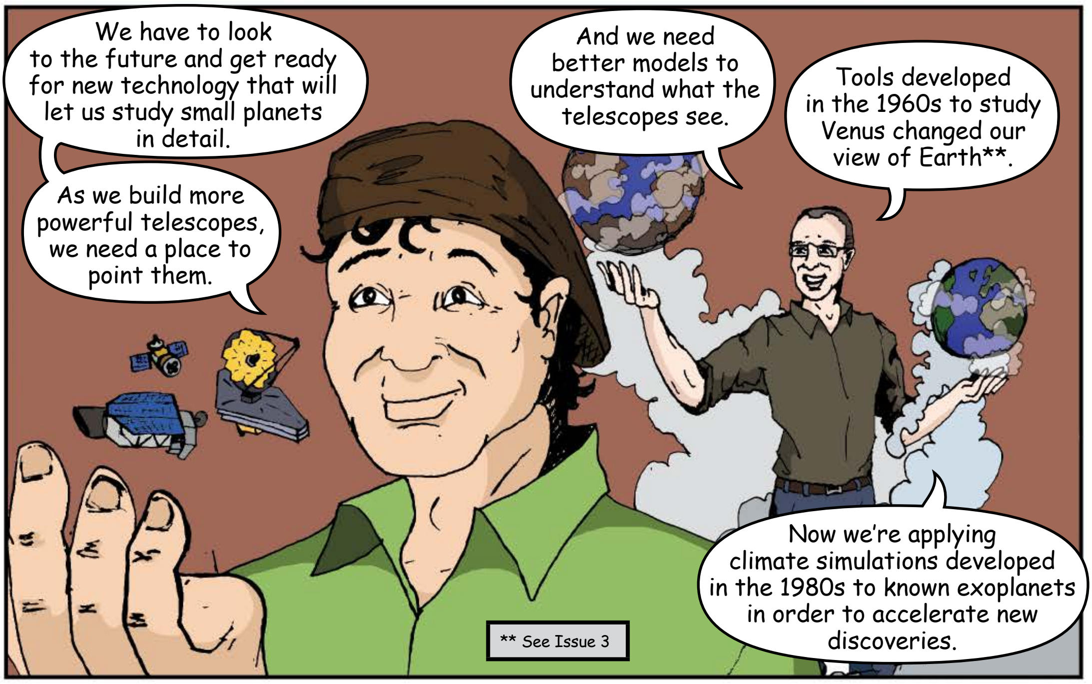


Free energy is an **anti**-biosignature.
If life had access to Mars' atmosphere, it would use that energy to survive.
We know that from watching life on Earth, and how it maintains the balance of things like oxygen, nitrogen, and water on our planet.
Life makes the composition of Earth's atmosphere possible.
"The low oxygen on Mars is what made me think the planet was lifeless back in the days of Viking." (20)*
*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.



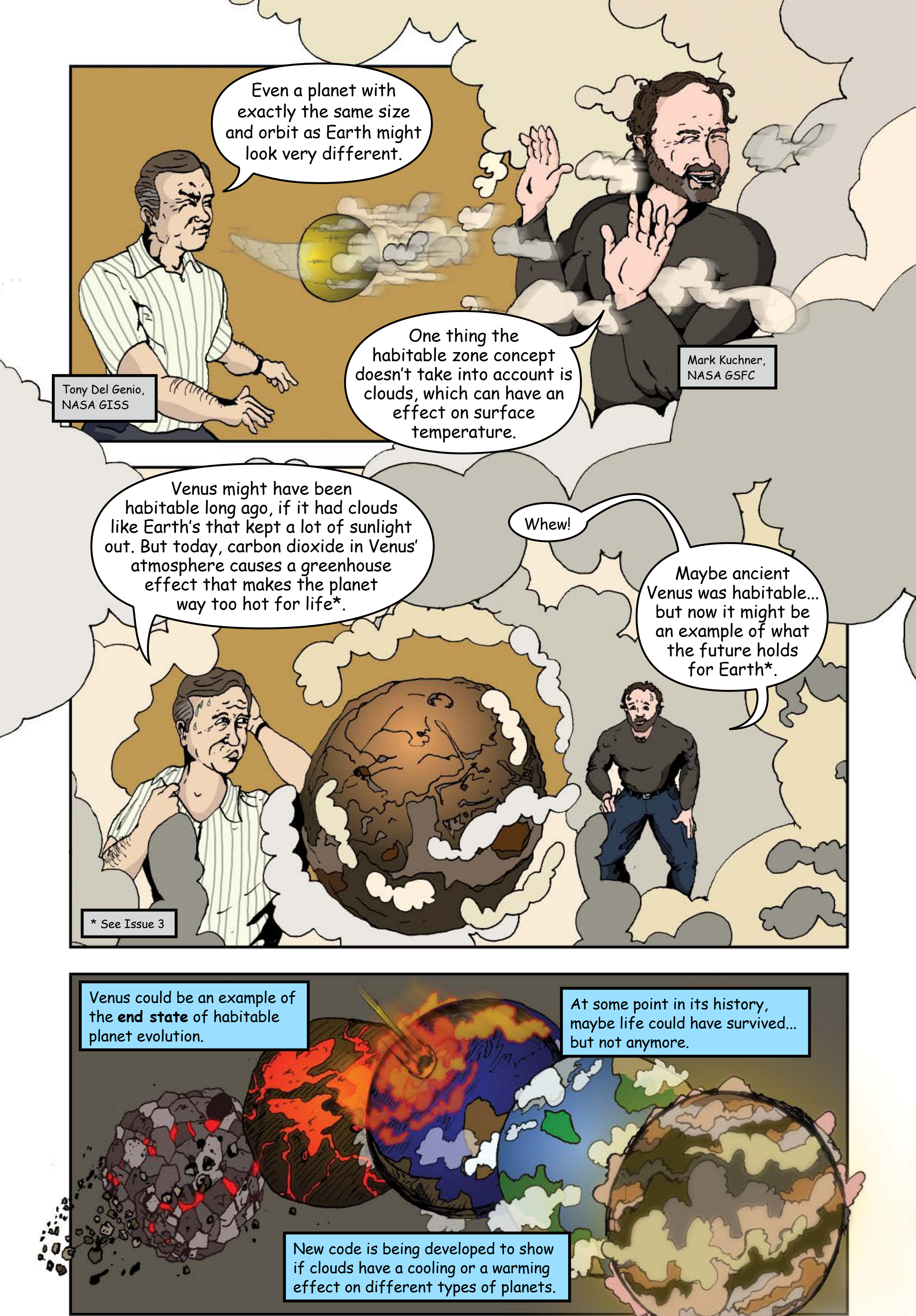
At a coffee shop in Seattle, 2010...
Uh-oh!...
What, is something wrong?
Uh... yeah.
More coffee?
No, not that...
Jen Domagal-Goldman, American Democracy Project
Oxygen doesn't have to come from life...
Turns out, you can get lots of oxygen without biology. (27)
Now we know multiple ways for making oxygen abiotically. (27, 28, 29, 30, 31)
ZAP!
ZAP!
For instance, energy from a young star can strip hydrogen away from water molecules...
POP!
POP!
...leaving only the oxygen behind.
POP!
Or, carbon dioxide can be broken apart by solar energy through photolysis*.
ZAP!
Now scientists had to look at what **other** features could act as a signal for life in an atmosphere.
*Chemical decomposition under the influence of light.

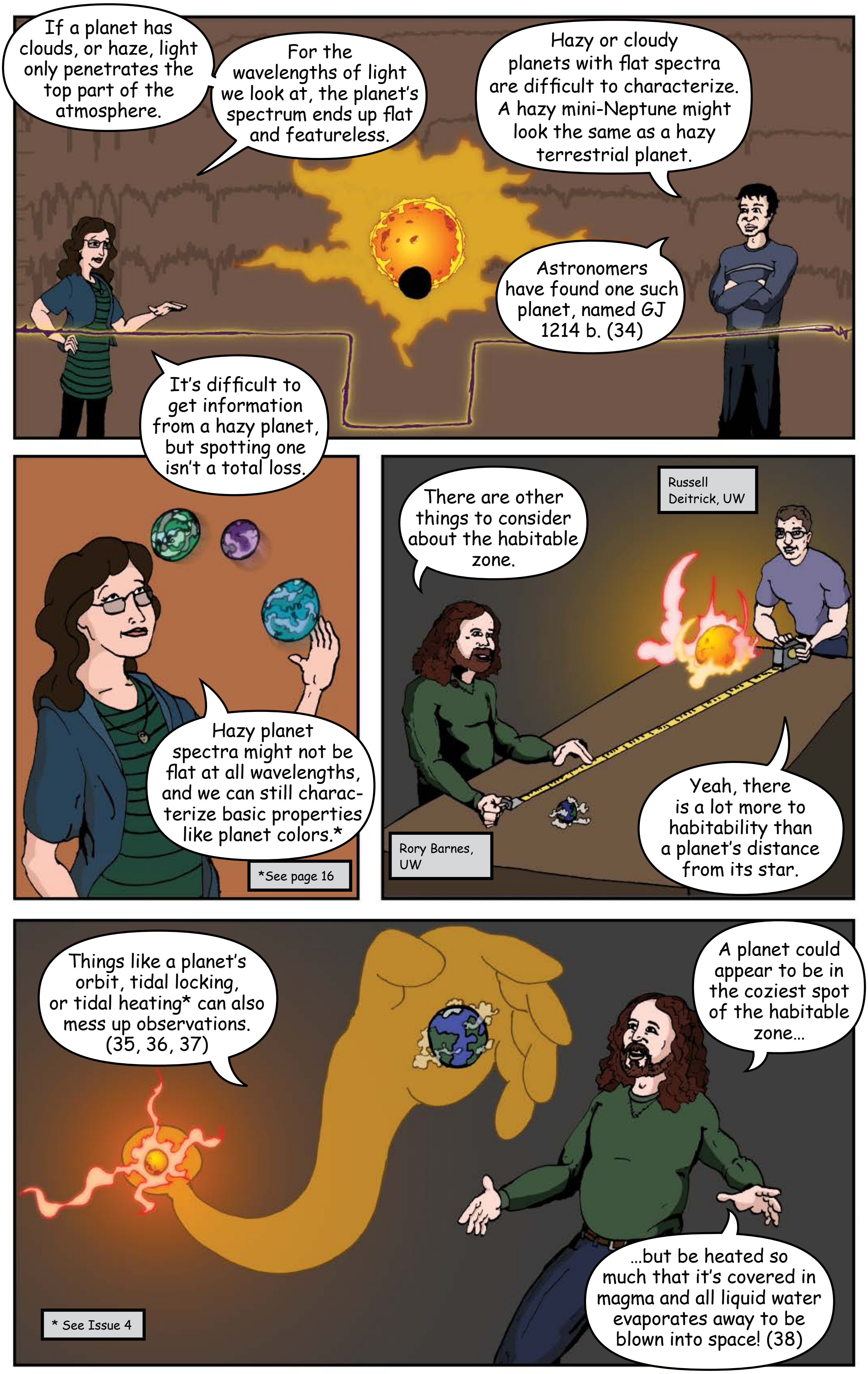

If the oxygen comes from photolysis, or some other process...
...maybe something else happens alongside that process that we can detect?
Then we could tell the difference between oxygen from biology, and oxygen from some-thing else.
We realized that we can't only think about how to identify life.
We 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). (32)
NExSS encourages collaboration among the four science communities supported by NASA's Science Mission Directorate.
Earth Science
Astrophysics
Heliophysics
Planetary Science.

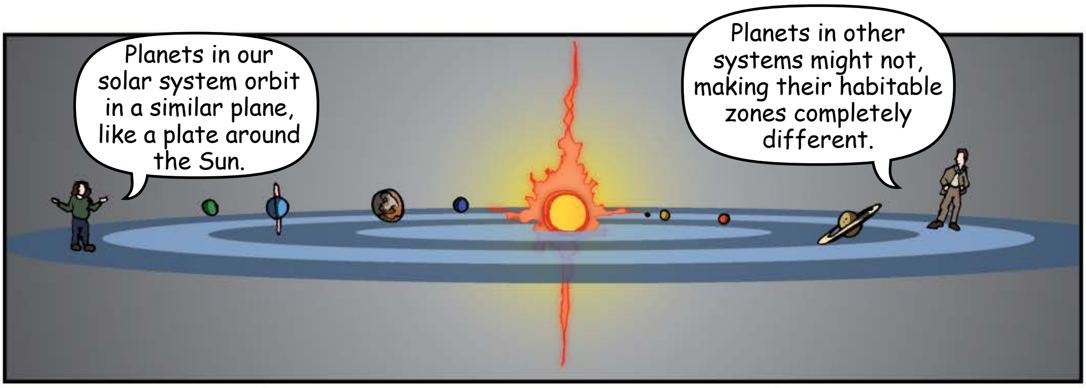

We have to look to the future and get ready for new technology that will let us study small planets in detail.
As we build more powerful telescopes, we need a place to point them.
And we need better models to understand what the telescopes see.
Tools developed in the 1960s to study Venus changed our 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 un-like Earth...
...how they interact with their stars...
...and their past or present habitability.
Eric Ford, Penn State
Steve Desch, Arizona State University

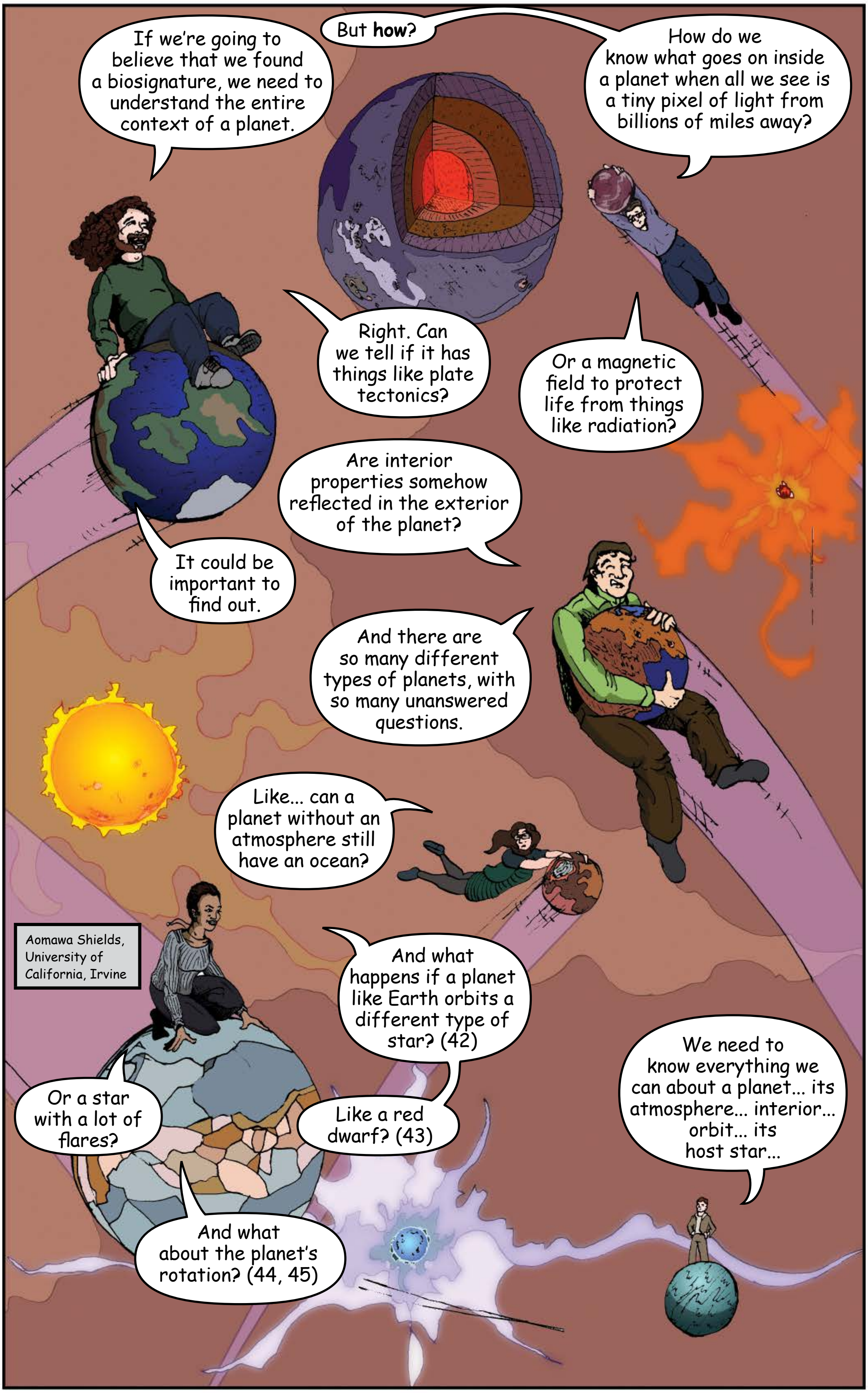

With new ideas from even more scientists, let's look again at the 'habitable zone.'
The habitable zone concept lets us start our search where life is most likely to be, but it doesn't guarantee habitability. (33)
The 'habitable zone' makes things sound easy. We just need a small planet with an orbit 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.
These findings indicate that we might find a terrestrial planet that theoretically sits in the habitable zone... yet isn't actually habitable.

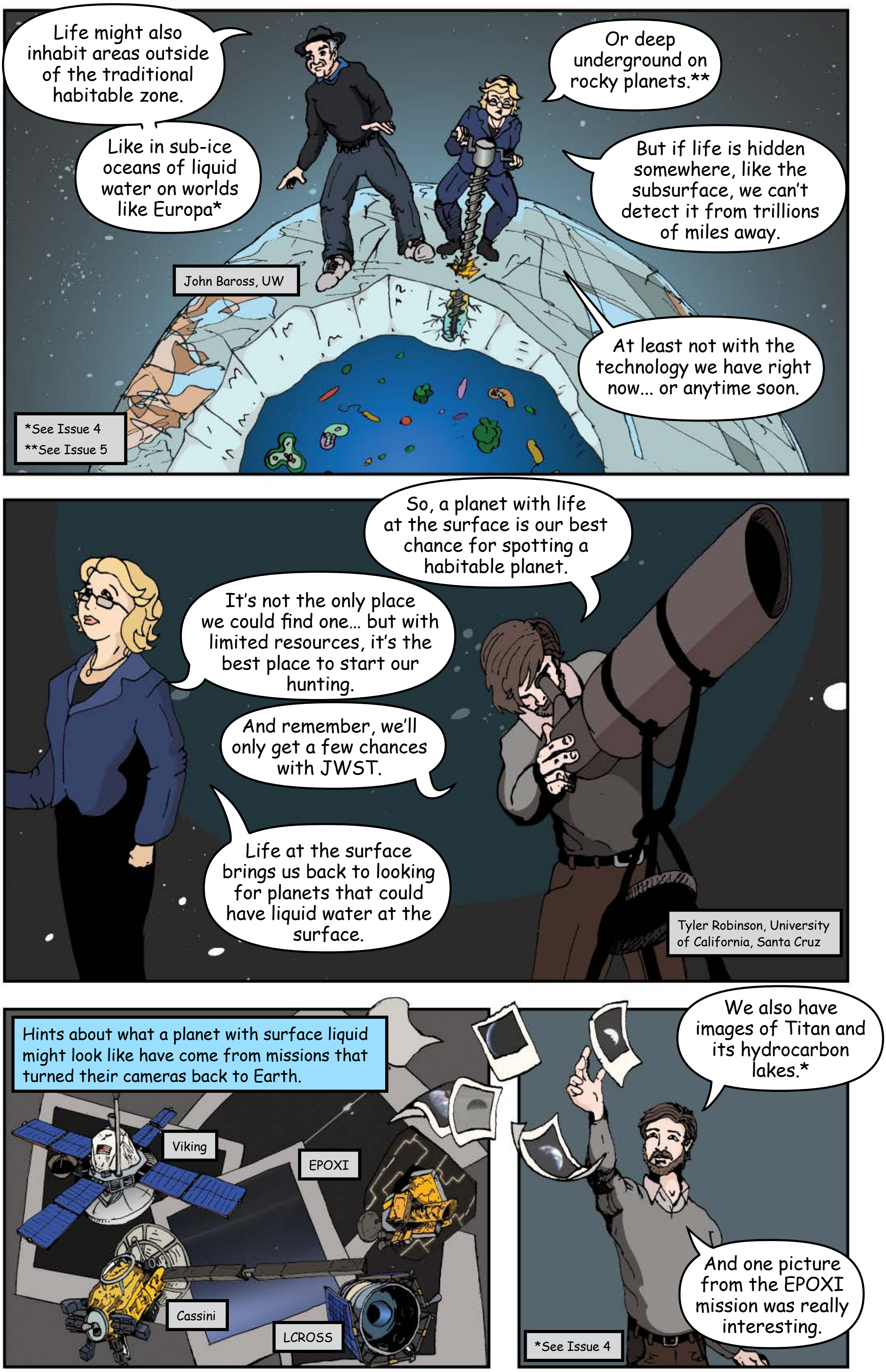

Even a planet with exactly the same size and orbit as Earth might look very different.
Tony Del Genio, NASA GISS
Mark Kuchner, NASA GSFC
One thing the habitable zone concept doesn't take into account is clouds, which can have an effect on surface temperature.
Venus might have been habitable long ago, 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
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.
New code is being developed to show if clouds have a cooling or a warming effect on different types of planets.

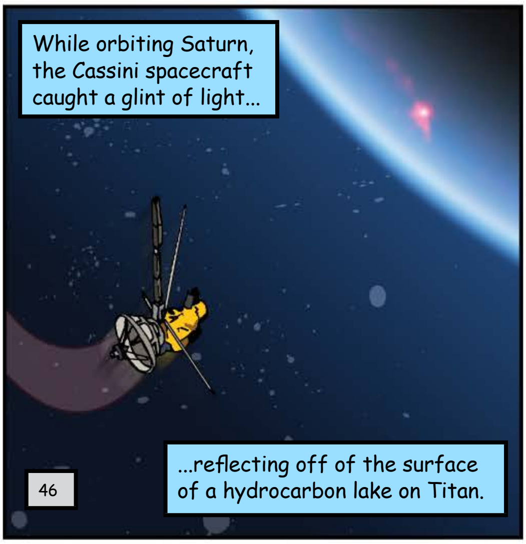

If a planet has clouds, or haze, light only penetrates the top part of the atmosphere.
For the wavelengths of light we look at, the planet's spectrum ends up flat and featureless.
Hazy or cloudy planets with flat spectra are difficult to characterize. A hazy mini-Neptune might look the same as a hazy terrestrial planet.
Astronomers have found one such planet, named GJ 1214 b. (34)
It's difficult to get information from a hazy planet, but spotting one isn't a total loss.
Hazy planet spectra might not be flat at all wavelengths, and we can still charac-terize basic properties like planet colors.*
*See page 16
Russell Deitrick, UW
There are other things to consider about the habitable zone.
Yeah, there is a lot more to habitability than a planet's distance from its star.
Rory Barnes, UW
Things like a planet's orbit, tidal locking, or tidal heating* can also mess up observations. (35, 36, 37)
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! (38)
* 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.

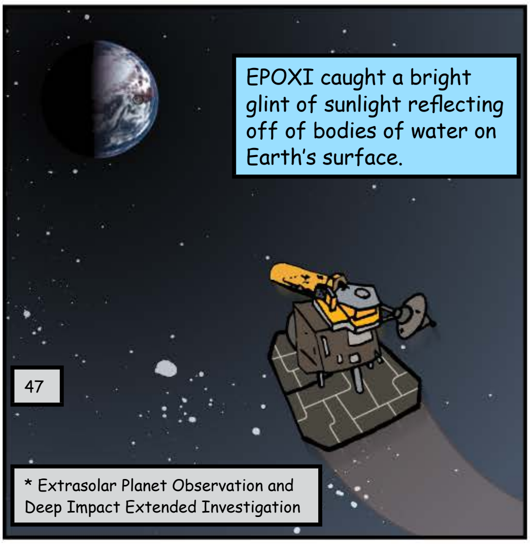

A planet on a crazy orbit might transit its star…
... so we can spot it...
...but we might not realize that it swings both so far away from and so close to its star during its orbit that it is uninhabitable for life as we know it. (39)
WHOOSH!!!
Whoa!
The gravity of a planet pulls on its star (and vice versa), and planets also pull on each other.
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! (40, 41)
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 billions of miles away?
Right. Can we tell if it has things like plate tectonics?
Or a magnetic field to protect life from things like 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? (42)
Or a star with a lot of flares?
Like a red dwarf? (43)
We need to know everything we can about a planet... its atmosphere... interior... orbit... its host star...
And what about the planet's rotation? (44, 45)


Life might also inhabit areas outside of the traditional habitable zone.
Like in sub-ice oceans of liquid water on worlds like Europa*
John Baross, UW
Or deep underground on rocky planets.**
But 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.
*See Issue 4
**See Issue 5
So, a planet with life at the surface is our best chance for spotting a habitable planet.
It's not the only place we could find one... but with limited resources, it's the best place to start our hunting.
And remember, we'll only get a few chances with JWST.
Life at the surface brings us back to looking for planets that could have liquid water at the surface.
Tyler Robinson, University of California, Santa Cruz
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



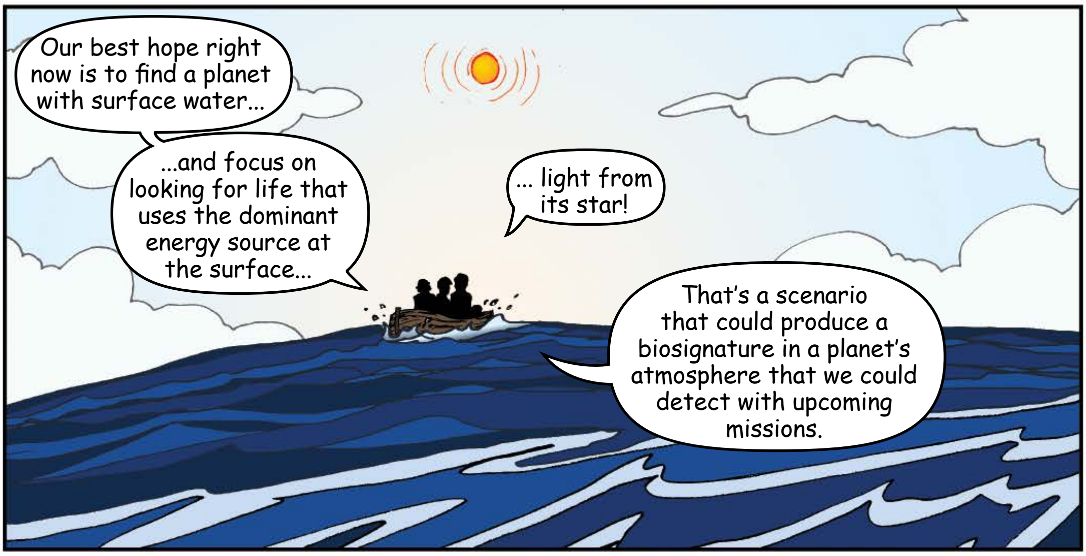
While orbiting Saturn, the Cassini spacecraft caught a glint of light...
...reflecting off of the surface of a hydrocarbon lake on Titan.
46



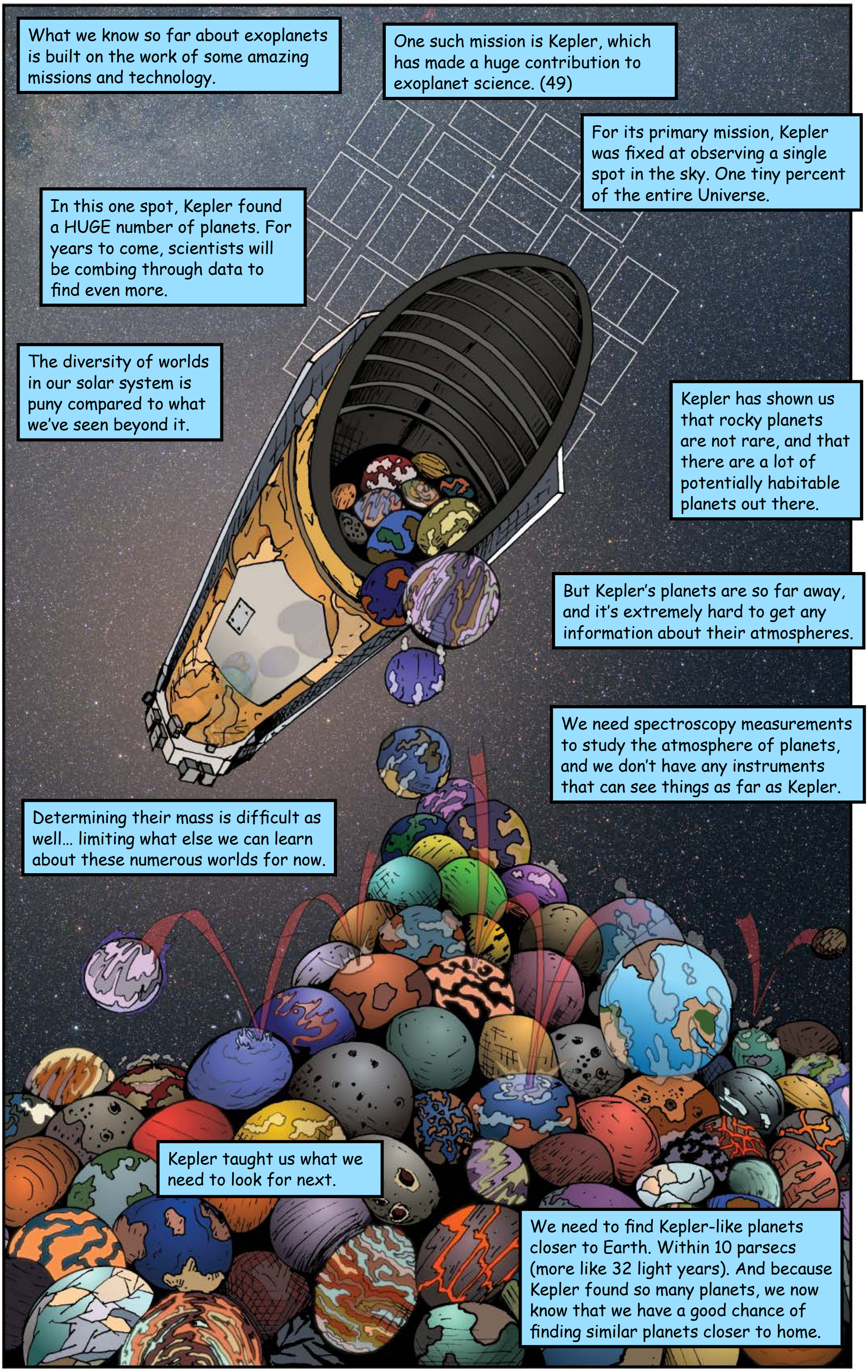
EPOXI caught a bright glint of sunlight reflecting off of bodies of water on Earth's surface.
47
* Extrasolar Planet Observation and Deep Impact Extended Investigation

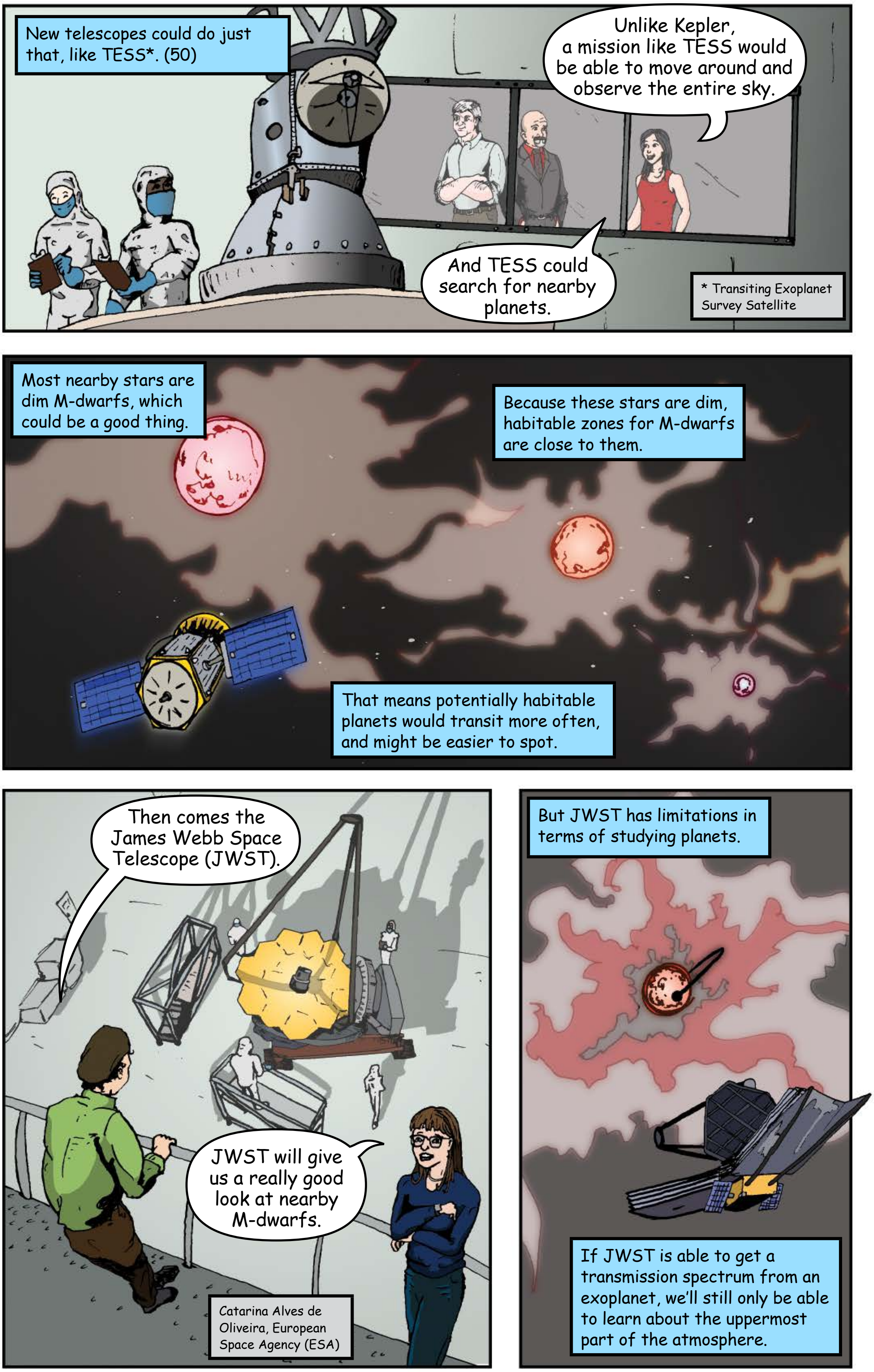
Could we detect a similar glint of light with our telescopes? (48)
Maybe...
... such a tiny amount of light added to the light of the star...
It wouldn't prove there's life, but liquid is a big step.
Ralf Jaumann, Deutsches Zentrum für Luft- und Raumfahrt (DLR)

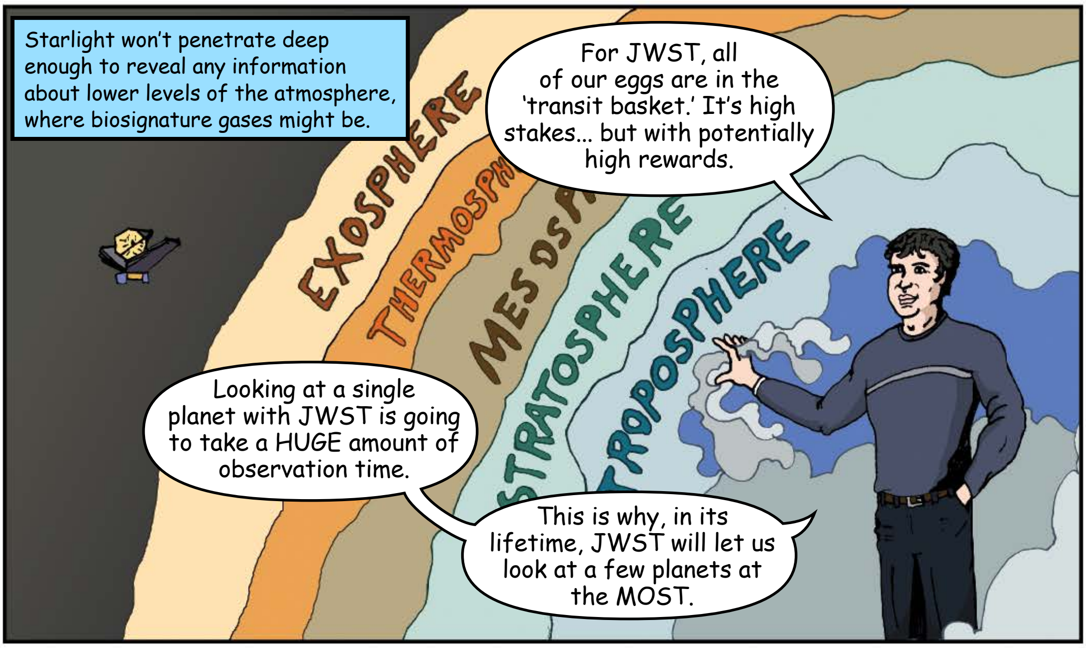
It would certainly help us narrow our search.
Particularly if the liquid is **water**.
Surface water could mean life at the surface.
Where we might stand a chance of detecting it!

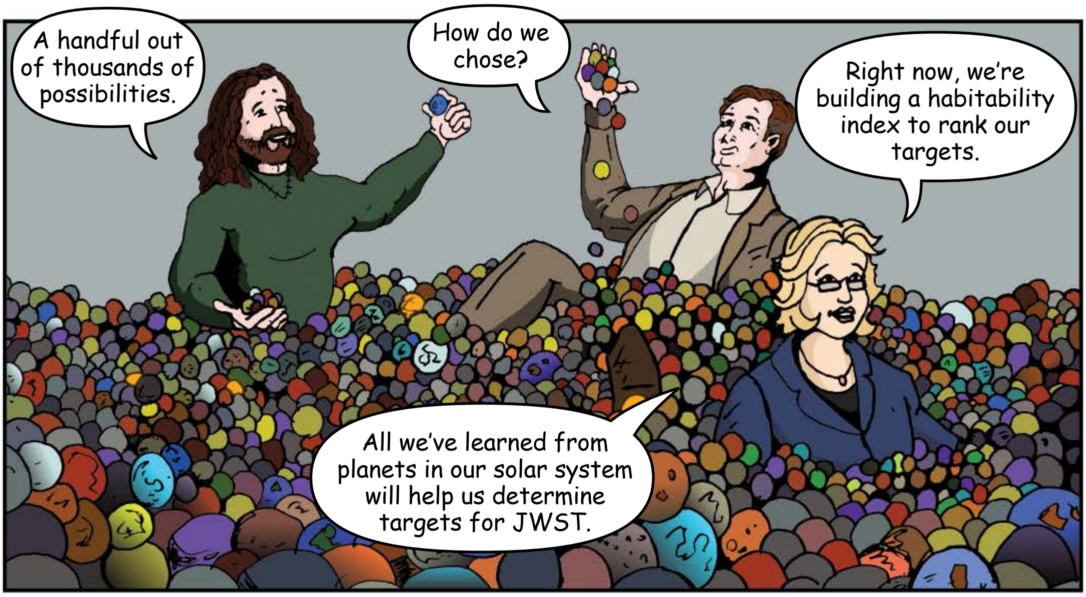


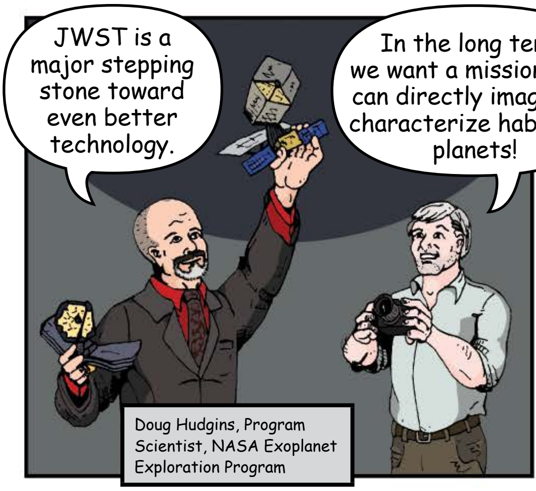
Our best hope right now is to find a planet with surface water...
...and focus on looking for life that uses the dominant energy source at the surface...
... light from its star!
That's a scenario that could produce a biosignature in a planet's atmosphere that we could detect with upcoming missions.


What we know so far about exoplanets is built on the work of some amazing missions and technology.
One such mission is Kepler, which has made a huge contribution to exoplanet science. (49)
For its primary mission, 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. For years to come, scientists will be combing through data to find even more.
The diversity of worlds in our solar system is puny compared to what we've seen beyond it.
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 so far away, and it's extremely hard to get any information about their atmospheres.
We need spectroscopy measurements to study the atmosphere of planets, and we don't have any instruments that can see things as far as Kepler.
Determining their mass is difficult as well… limiting what else we can learn about these numerous worlds for now.
Kepler taught us what we need to look for next.
We need to find Kepler-like planets closer to Earth. Within 10 parsecs (more like 32 light years). And because Kepler found so many planets, we now know that we have a good chance of finding similar planets closer to home.


New telescopes could do just that, like TESS*. (50)
Unlike Kepler, a mission like TESS would be able to move around and observe the entire sky.
And TESS could 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, habitable zones for M-dwarfs are close to them.
That means potentially habitable planets would transit more often, and might be easier to spot.
Then comes the James Webb Space Telescope (JWST).
JWST will give us a really good look at nearby M-dwarfs.
Catarina Alves de Oliveira, European Space Agency (ESA)
But JWST has limitations in terms of studying planets.
If JWST is able to get a transmission spectrum from an exoplanet, we'll still only be able to learn about the uppermost part of the atmosphere.

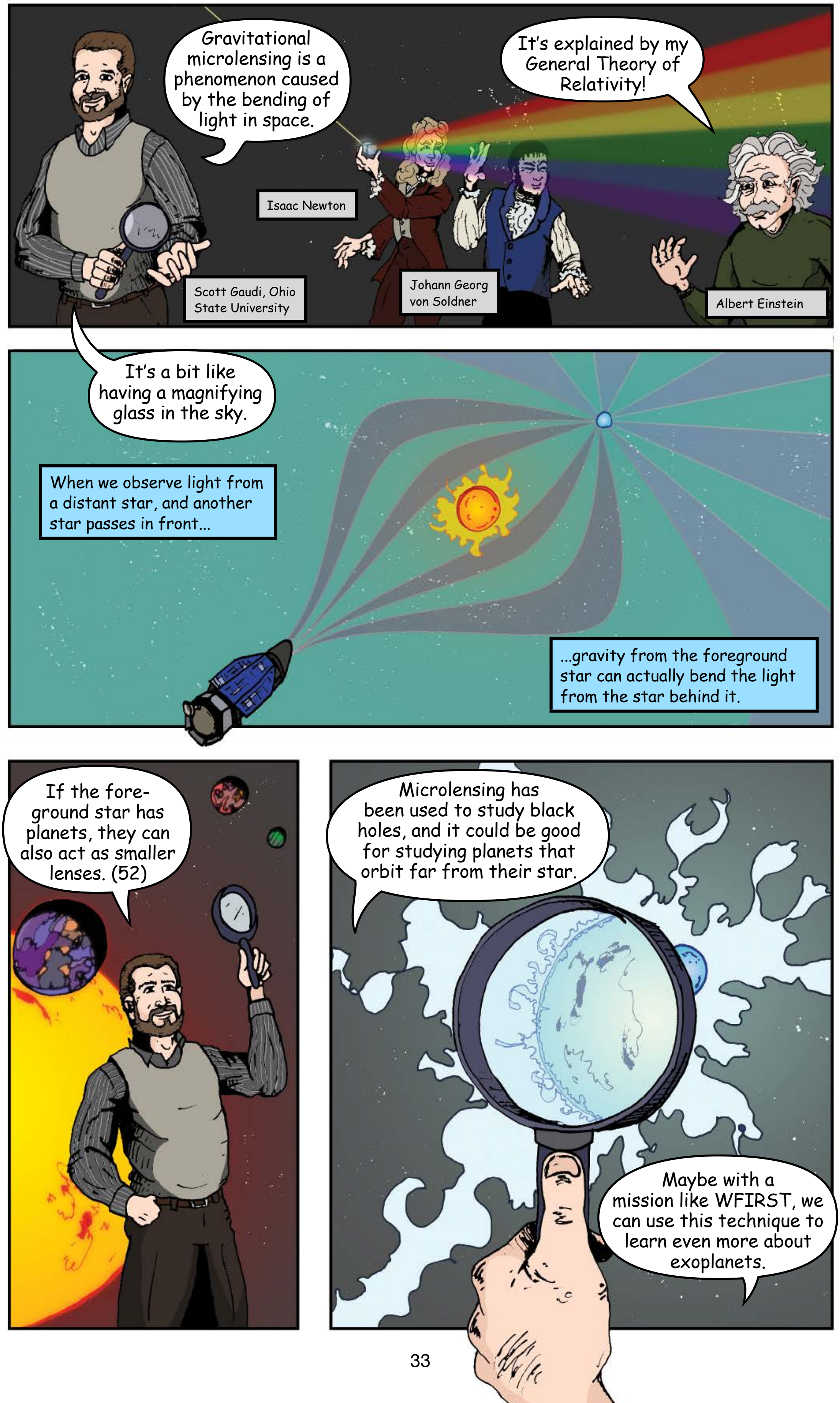

Starlight won't penetrate deep enough to reveal any information about lower levels of the atmosphere, where biosignature gases might be.
EXOSPHERE
THERMOSPH
MESOSP
STRATOSPHERE
TROPOSPHERE
For JWST, all of our eggs are in the 'transit basket.' It's high stakes... but with potentially high rewards.
Looking at a single planet with JWST is going to take a HUGE amount of observation time.
This is why, in its lifetime, JWST will let us look at a few planets at the MOST.

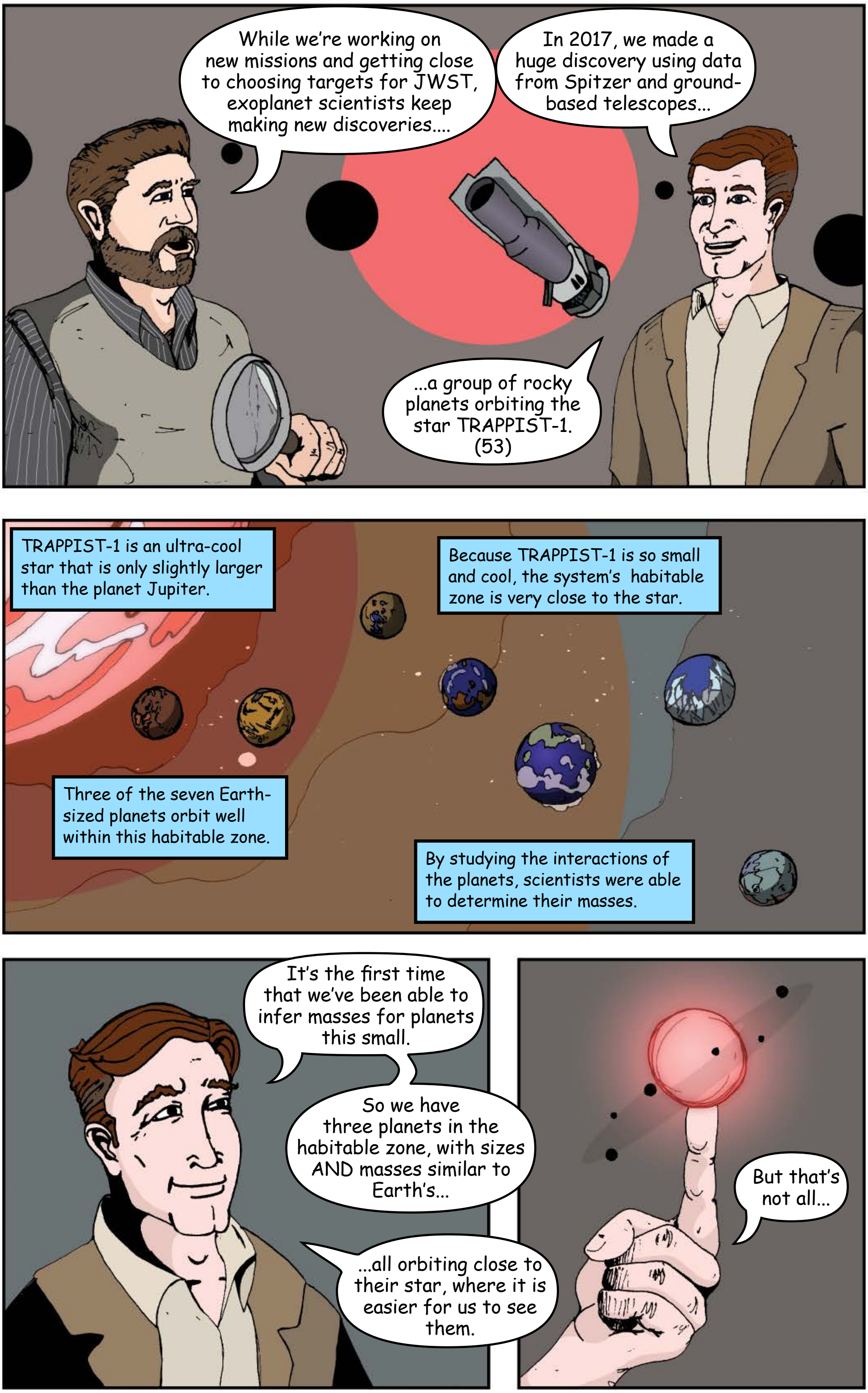

A handful out of thousands of possibilities.
How do we chose?
Right now, we're building a habitability index to rank our targets.
All we've learned from planets in our solar system will help us determine targets for JWST.


JWST is a major stepping stone toward even better technology.
In the long term, we want a mission that can directly image and characterize habitable planets!
Doug Hudgins, Program Scientist, NASA Exoplanet Exploration Program


We're still a long way from that goal...
...but each new mission gets us closer.
Karl Stapelfeldt, Exoplanet Exploration Program Office Chief Scientist at JPL

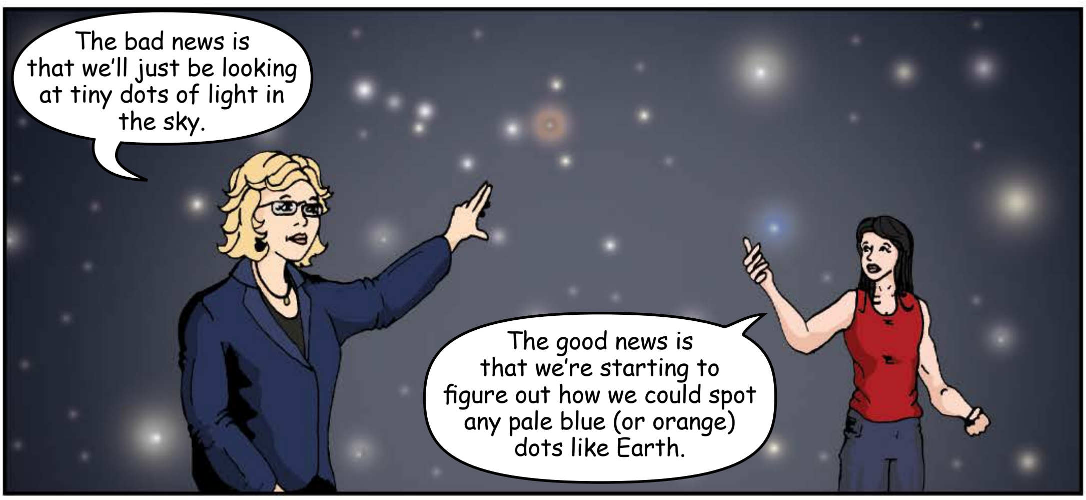
To take a picture of a planet, we have to block the huge amount of light coming from the star it orbits.
We get 10,000,000,000 photons from a star for every ONE photon from an Earth-like planet!
Technology like starshades and coronagraphs could help.
Starshades are separate structures that can block light...
...and coronagraphs are built into the telescope.
Early versions of this technology could be included on upcoming missions, like the planned WFIRST*.
WFIRST could make observations in the near-infrared (NIR) part of the spectrum. Its main camera would take images that are 100 times larger than those of the Hubble Space Telescope. (51)
A coronagraph on WFIRST wouldn't be used with the main camera, but it could still be powerful enough for us to image gas giant planets in visible light.
As always, viewing gas giants is where we'll start, because they're easier to see.
Over time, we'll perfect the technique and study smaller and smaller planets.
With its main camera, a mission like WFIRST could also use new planet-hunting techniques, like gravitational microlensing. (51)
* Wide Field Infrared Survey Telescope

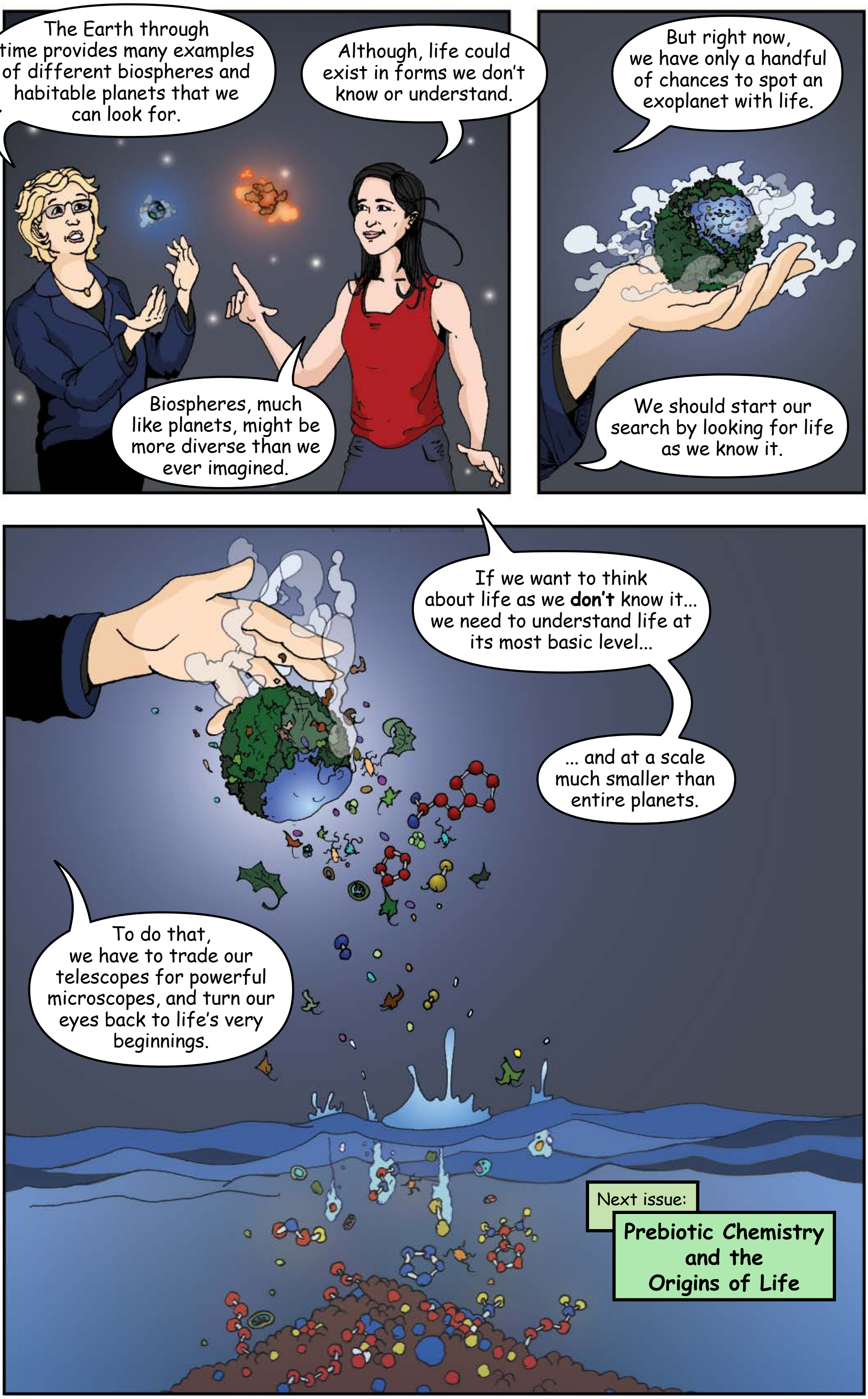

Gravitational microlensing is a phenomenon caused by the bending of light in space.
It's explained by my General Theory of Relativity!
Isaac Newton
Scott Gaudi, Ohio State University
Johann Georg von Soldner
Albert Einstein
It's a bit like having a magnifying glass in the sky.
When we observe light from 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. (52)
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 WFIRST, we can use this technique to learn even more about exoplanets.


While we're working on new missions and getting close to choosing targets for JWST, exoplanet scientists keep making new discoveries....
In 2017, we made a huge discovery using data from Spitzer and ground-based telescopes...
...a group of rocky planets orbiting the star TRAPPIST-1. (53)
TRAPPIST-1 is an ultra-cool star that is only slightly larger than the planet Jupiter.
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's the first time that we've been able to infer masses for planets this small.
So we have 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.
But that's not all...


Another amazing thing is that they are close, only 40 light years away! (54)
Aki Roberge, NASA GSFC
Right! We might actually be able to study their atmospheres with telescopes we have TODAY.
And, of course, they could be great candidates for the technology we're building right now.
Michaël Gillon, Université de Liège


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


The bad news is that we'll just be looking at tiny dots of light in the sky.
The good news is that we're starting to figure out how we could spot any pale blue (or orange) dots like Earth.


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

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46. This image shows the first flash of sunlight reflected off a lake on Saturn's moon Titan. The glint off a mirror-like surface is known as a specular reflection, and was detected by the visual and infrared mapping spectrometer (VIMS) on NASA's Cassini spacecraft on July 8, 2009. Image credit: NASA/JPL/University of Arizona/DLR
47. A sun glint on Earth is captured (center of the black circle) in the middle frame of this series of images taken by NASA's Deep Impact spacecraft as it looked at the north pole. Image Credit: Don Lindler, Sigma Space Corporation/GSFC
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