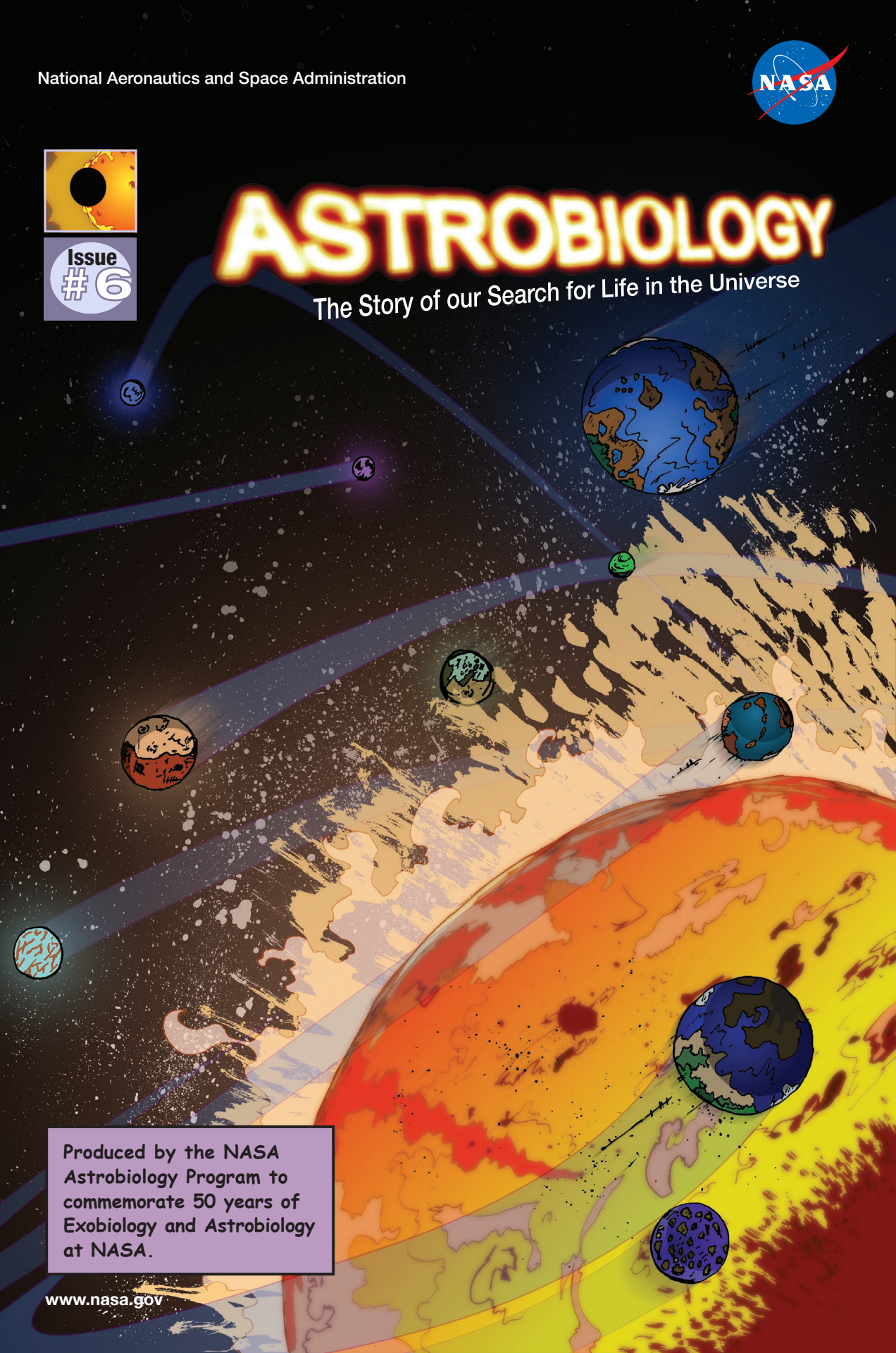


ASTROBIOLOGY

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.

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.

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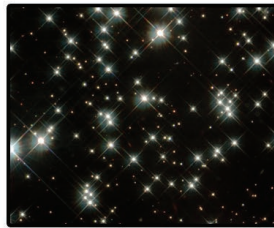
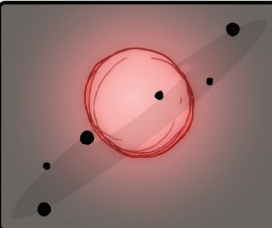
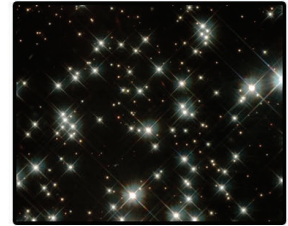
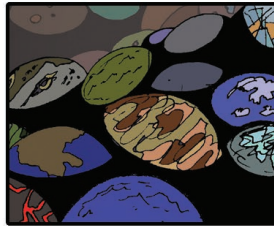
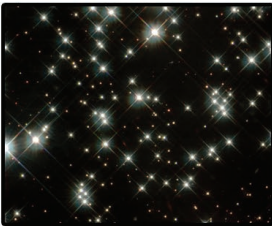
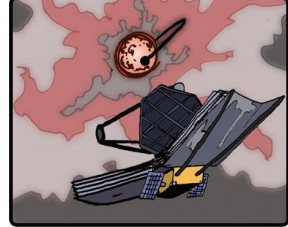
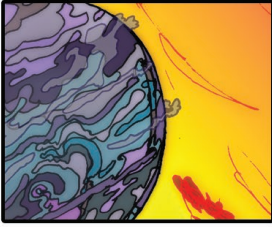
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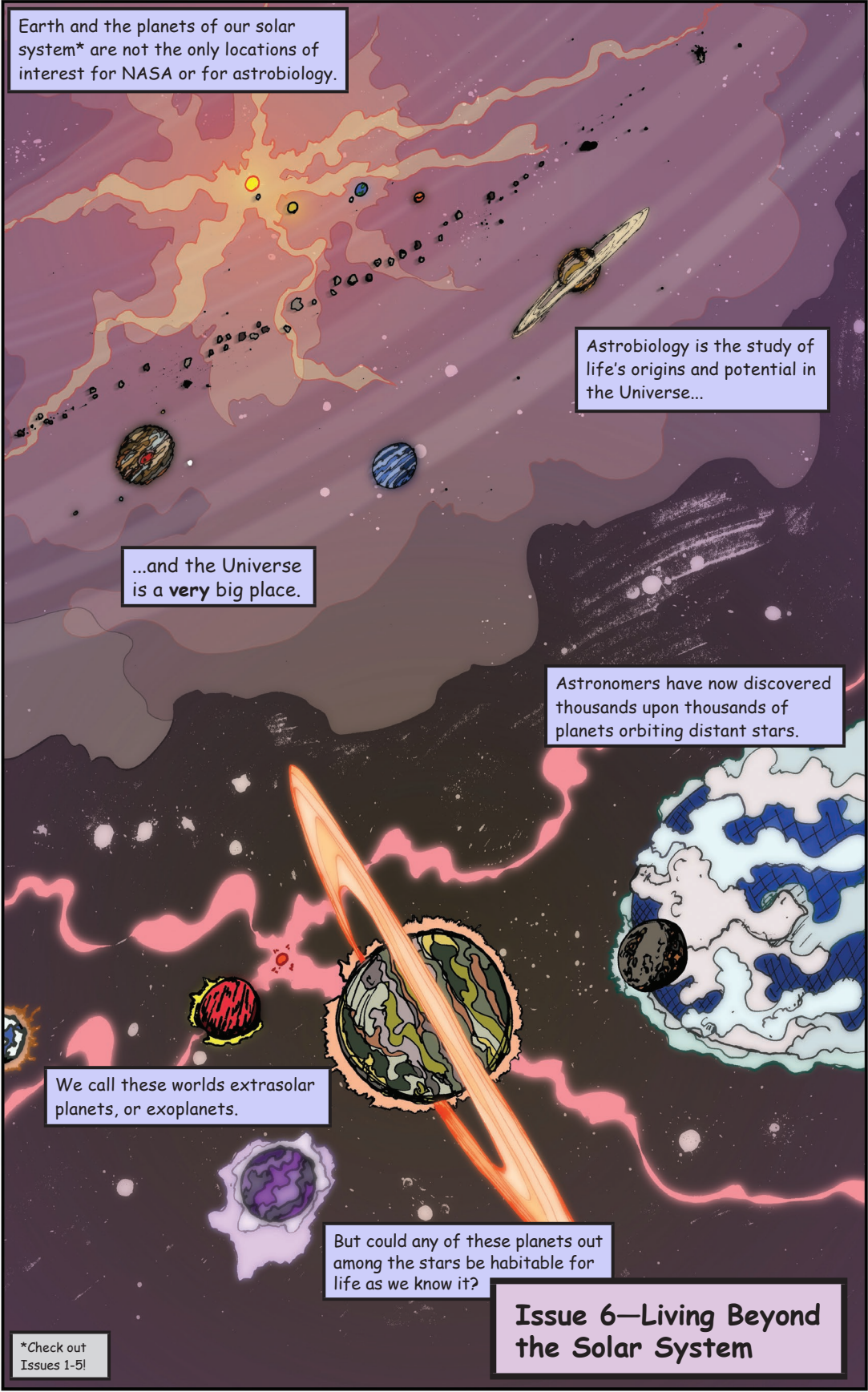
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Issue #6—Living Beyond the Solar System



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?

*Check out Issues 1-5!

Issue 6—Living Beyond the Solar System

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)

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.*

I believe in a 'plurality of worlds.'

For centuries, scientists and philosophers argued about the possibility of extrasolar planets.

There are countless Earths rotating around their suns in exactly the same way as the planets of our system.

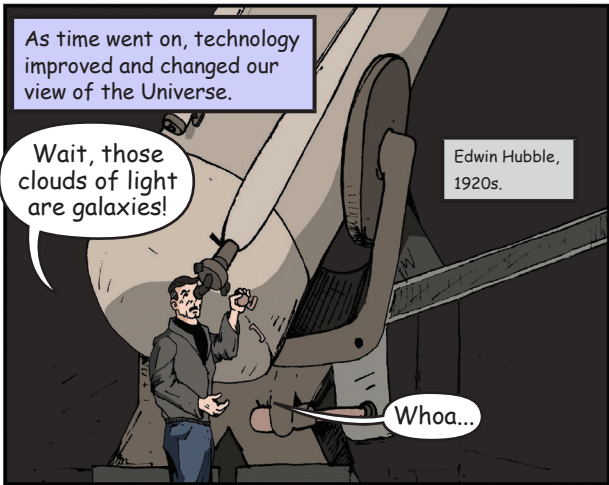
Giordano Bruno, 1548-1600. (3)

*see Issue #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.

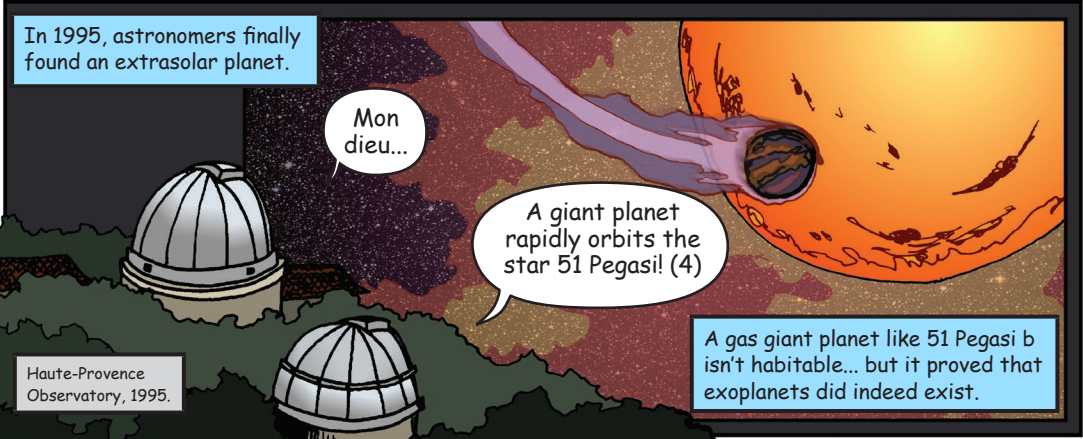
Wait, those clouds of light are galaxies!

Edwin Hubble, 1920s.

Whoa...



...that is a lot of stars.



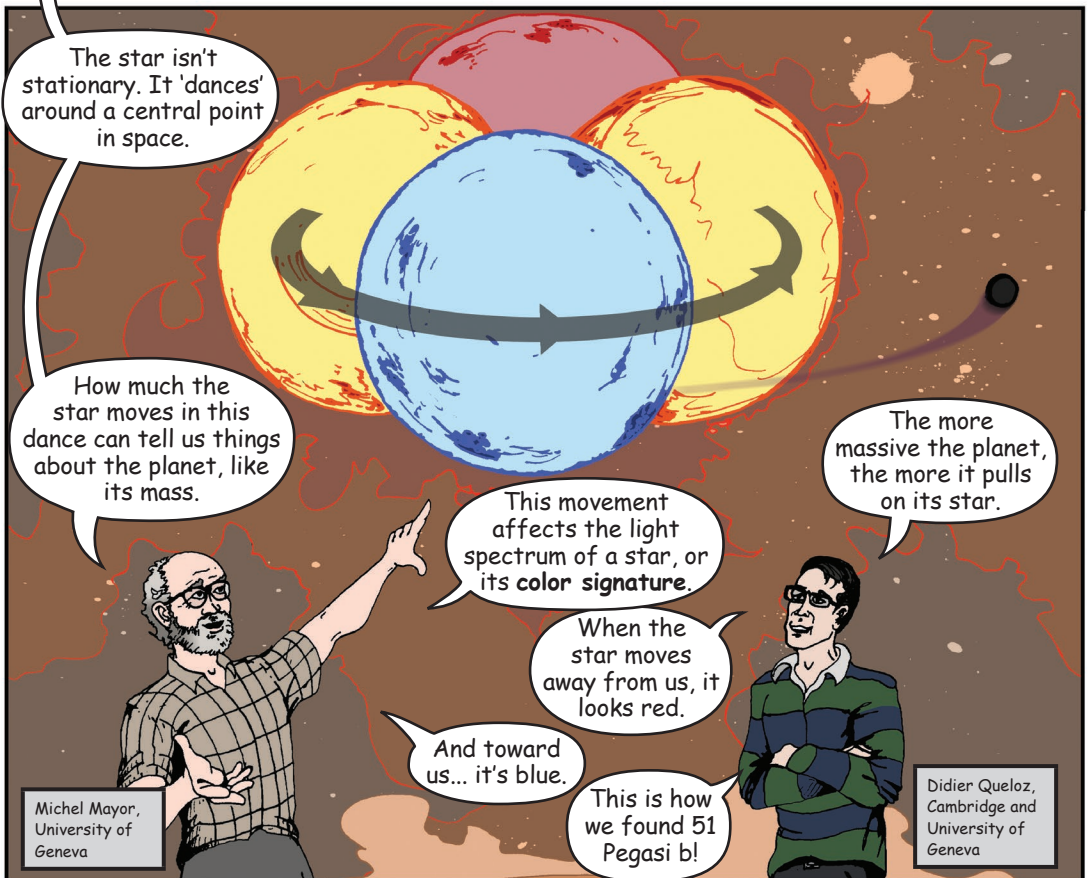
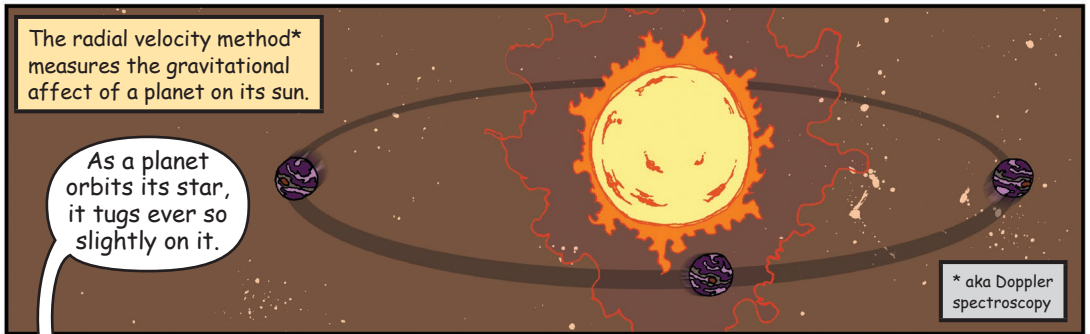
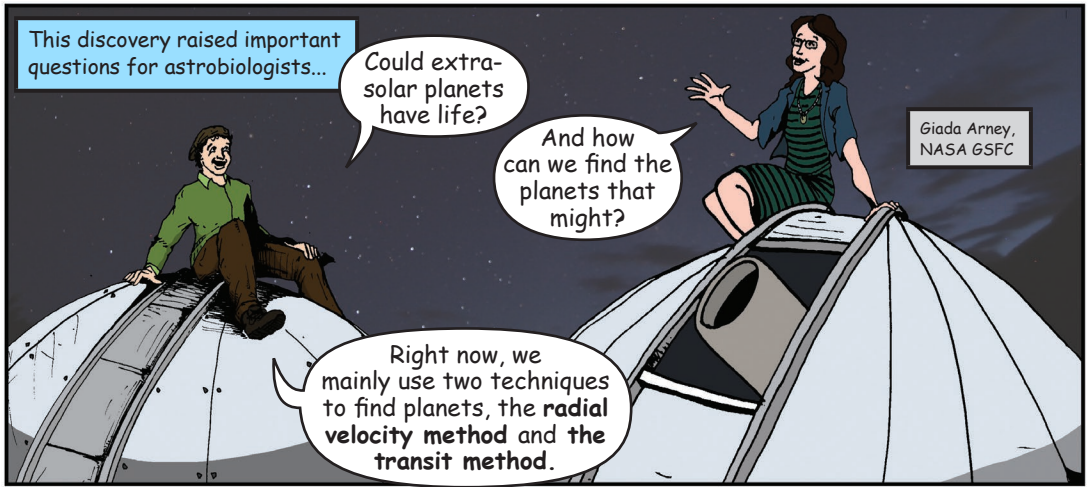
In 1995, astronomers finally found an extrasolar planet.

Mon dieu...

A giant planet rapidly orbits the star 51 Pegasi! (4)

A gas giant planet like 51 Pegasi b isn't habitable... but it proved that exoplanets did indeed exist.

Haute-Provence Observatory, 1995.



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.

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.

Spitzer Space Telescope (NASA - 2003)

Hubble Space Telescope (NASA - 1990)

And bizarre worlds unlike anything we'd seen before.

Things started to get very interesting for astrobiologists.

Finding small, rocky planets raised questions about whether or not any could be habitable.

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.

...and answer the big question: can they support life?

With so many planets, we wanted to figure out what their climates might be like...

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)

Climatologists

Astrobiology includes scientists from many fields, and so does the VPL.

Atmospheric chemists

Biophysicists

Spectroscopists

Biologists

Virologists

Geochemists

Geophysicists

There are astronomers.

Molecular evolutionary biologists

Geomicrobiologists

Planetary scientists

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.

Mercury

Venus

**See Issues 2,3 & 5

Now, 'terrestrial' does not mean 'Earth-like' or habitable.

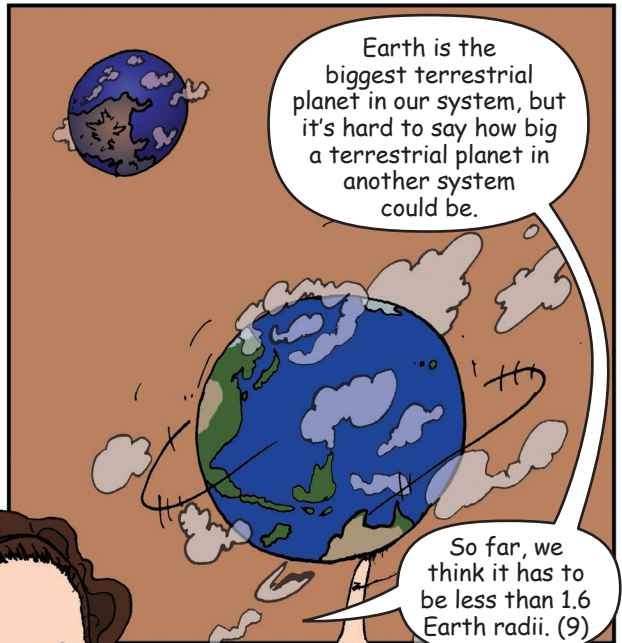
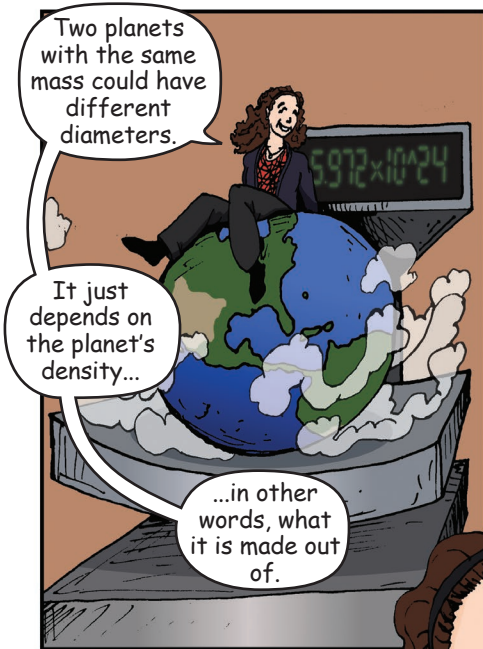
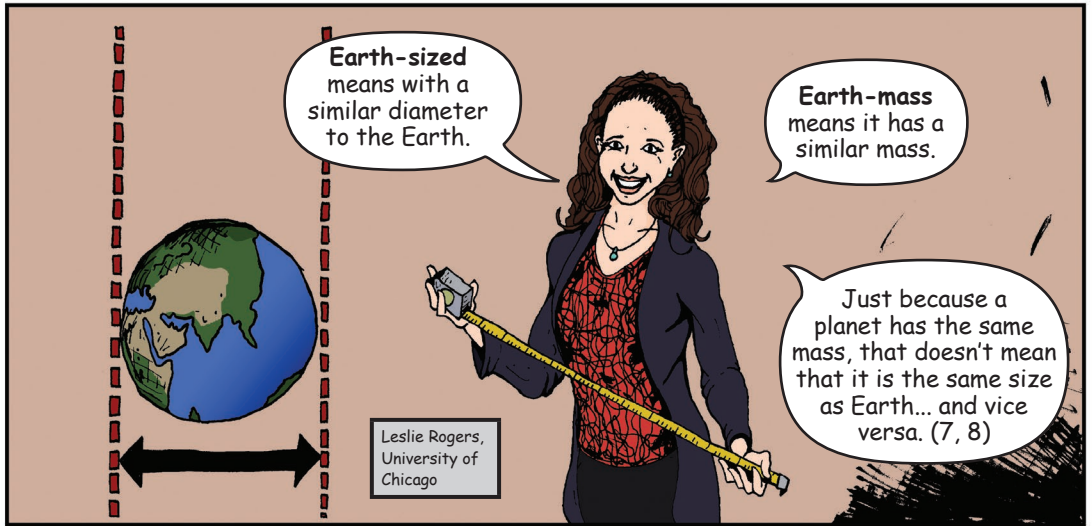
Our system has four terrestrial planets, but only one with life**.

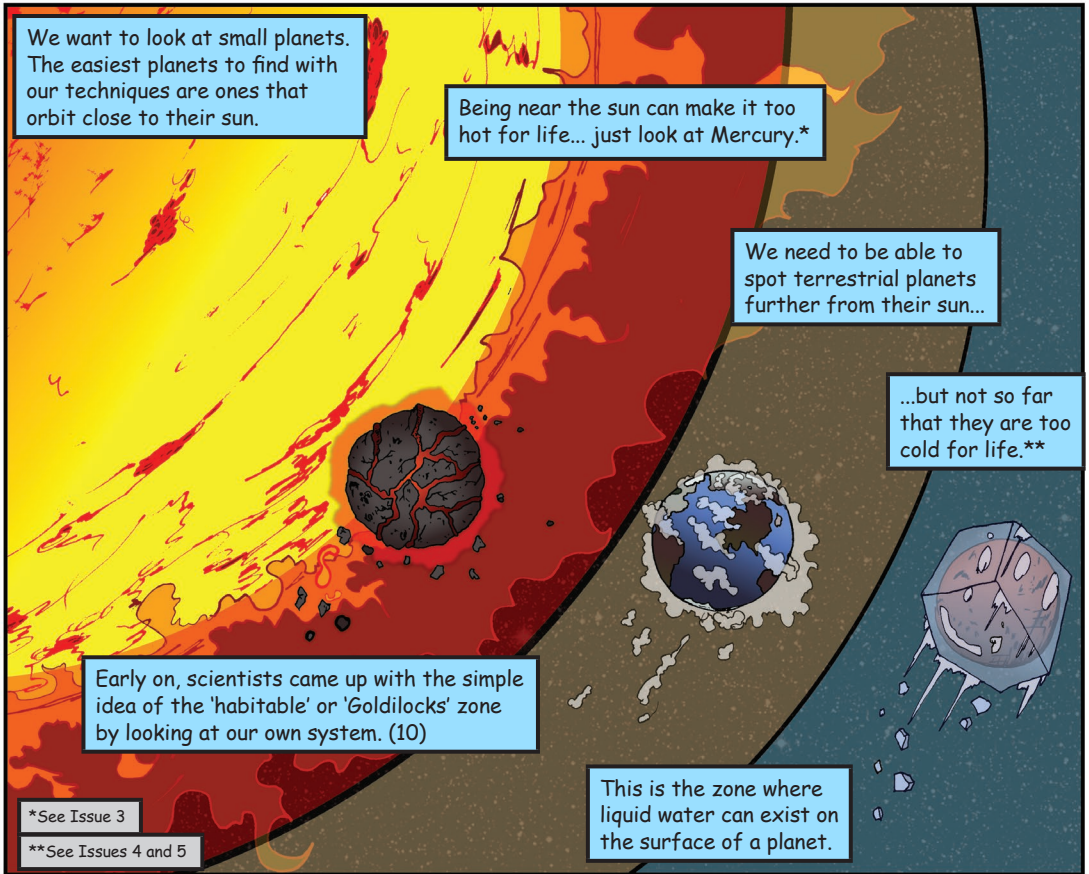
Earth

It means the planet is made of metals and rocks.

Mars

Bodies like the dwarf planet Pluto aren't terrestrial because they have so much ice and frozen material.





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...

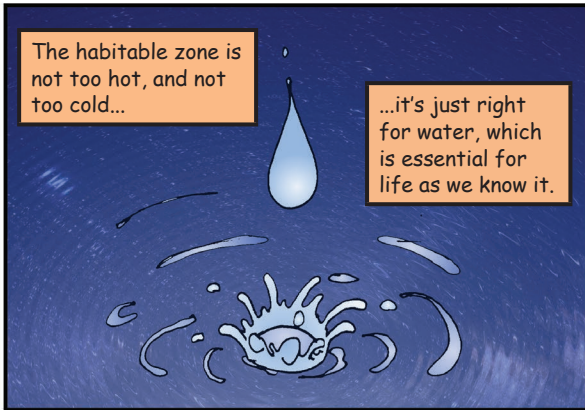
...but not so far that they are too cold for life.**

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

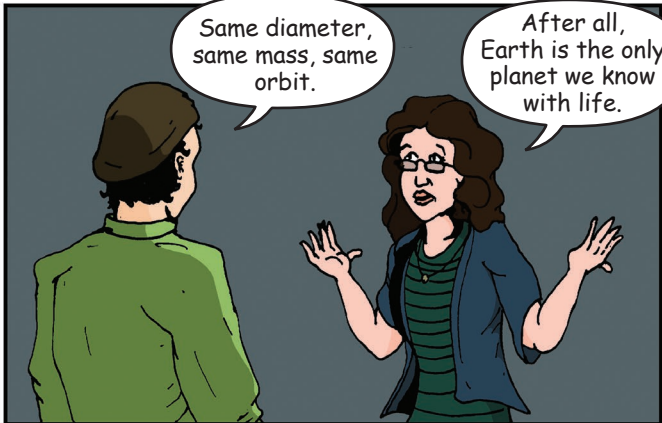


The habitable zone is not too hot, and not too cold...

...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.

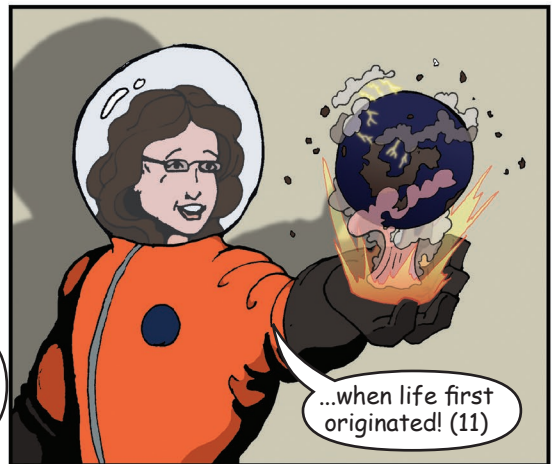
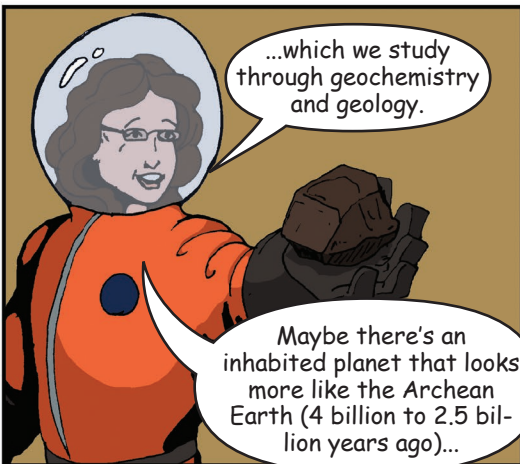
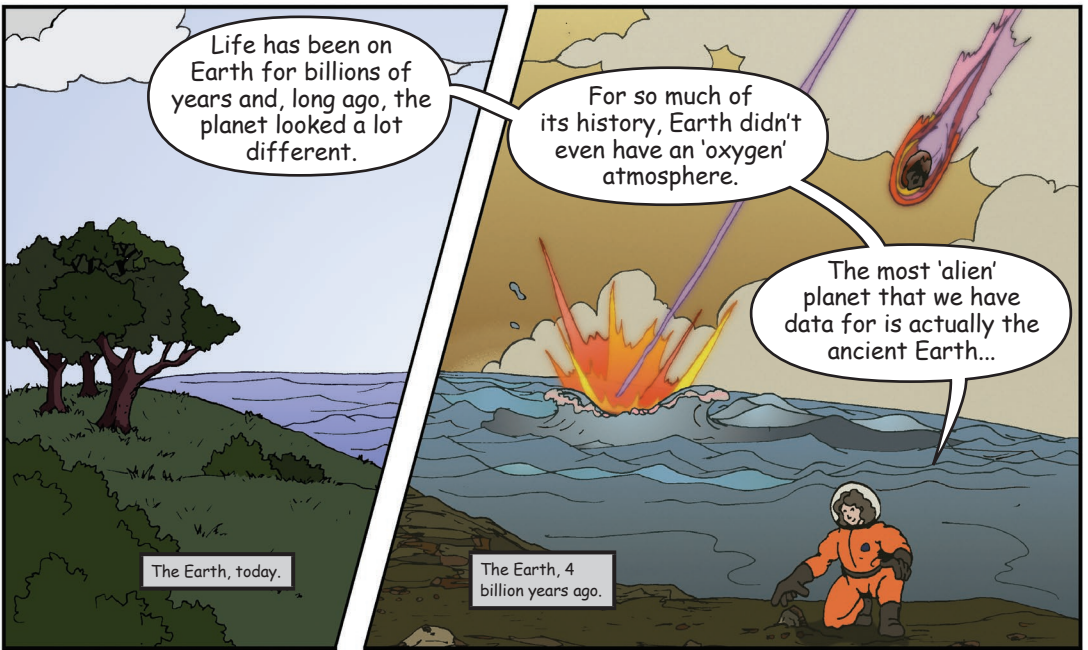
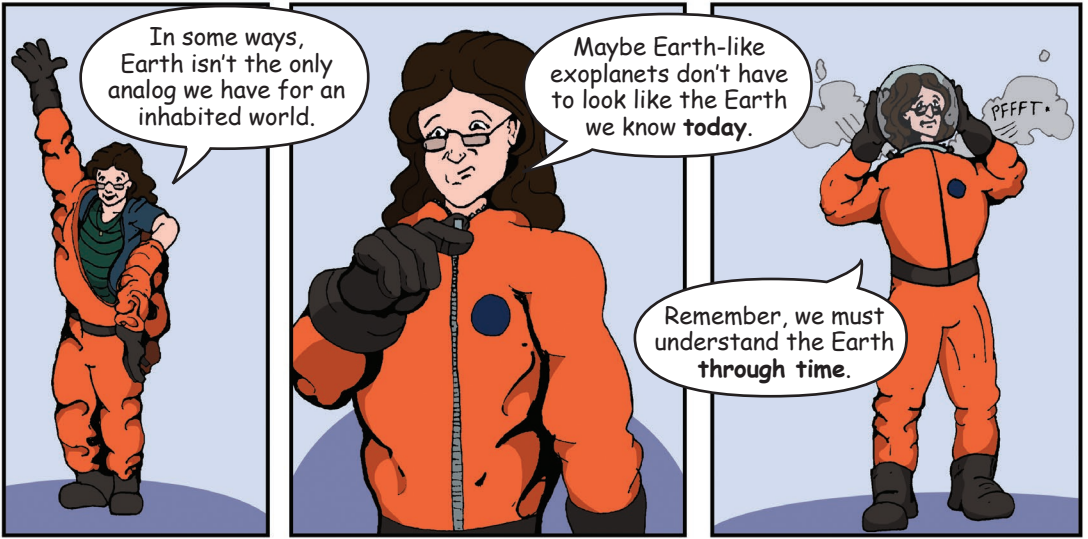


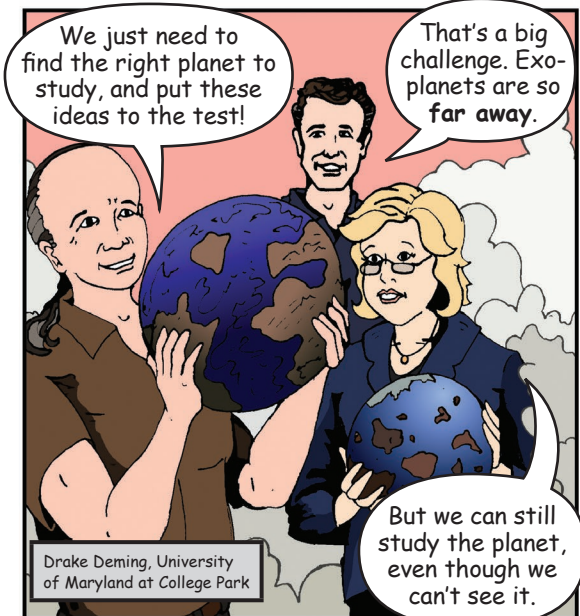
Same diameter, same mass, same orbit.

After all, Earth is the only planet we know with life.



Or is it...



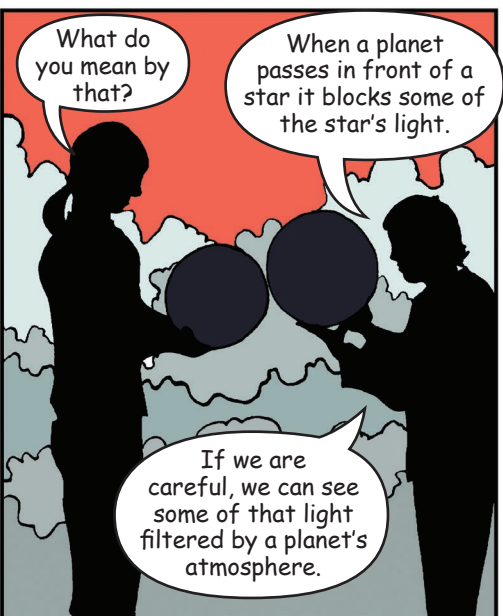


We just need to find the right planet to study, and put these ideas to the test!

That's a big challenge. Exoplanets 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.

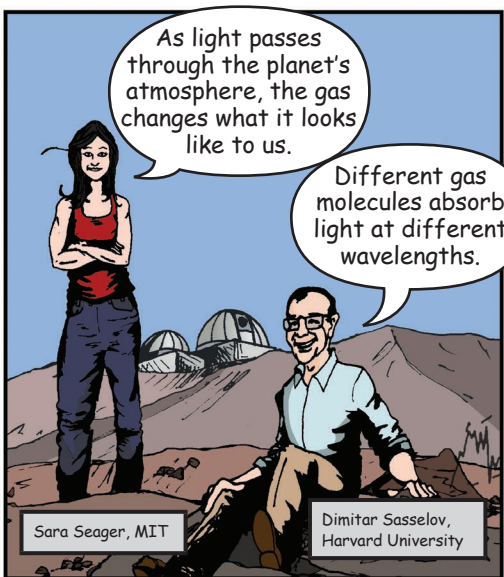
If we are careful, we can see some of that light filtered by a planet's atmosphere.



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)

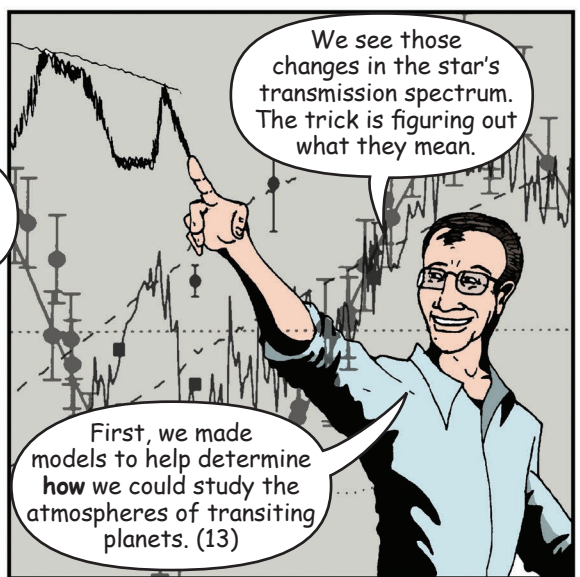


As light passes through the planet's atmosphere, the gas changes what it looks like to us.

Different gas molecules absorb light at different wavelengths.

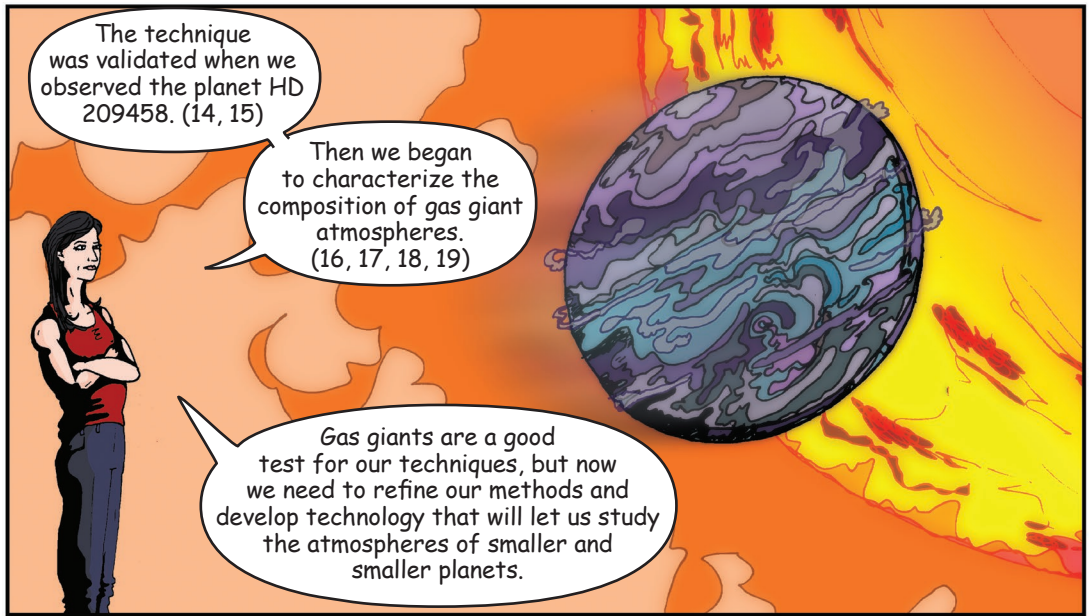
Sara Seager, MIT

Dimitar Sasselov, Harvard University



We see those changes in the star's transmission spectrum. The trick is figuring out what they mean.

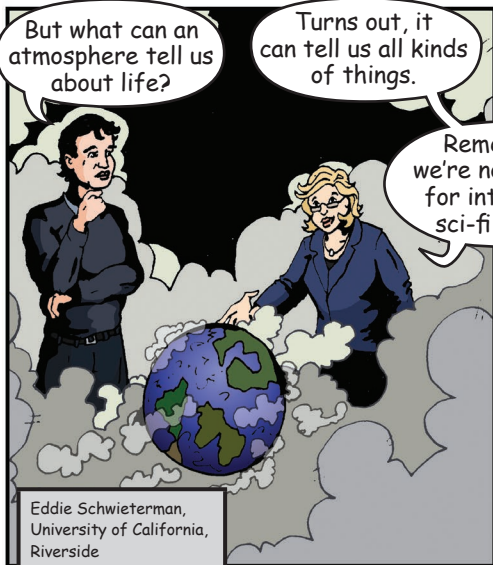
First, we made models to help determine how we could study the atmospheres of transiting planets. (13)



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.

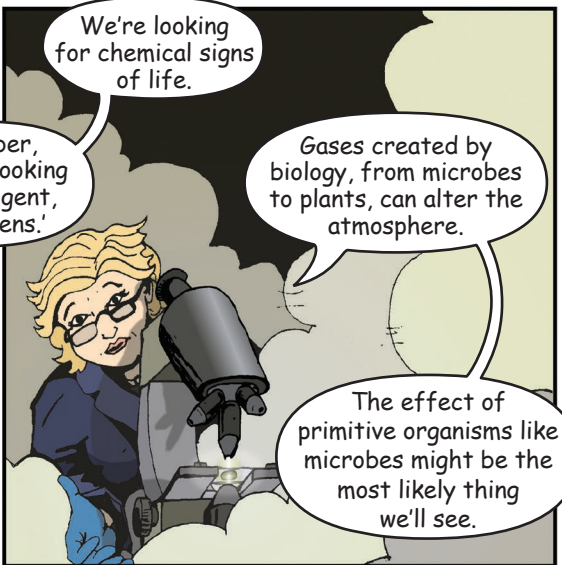


But what can an atmosphere tell us about life?

Turns out, it can tell us all kinds of things.

Remember, we're not looking for intelligent, sci-fi 'aliens.'

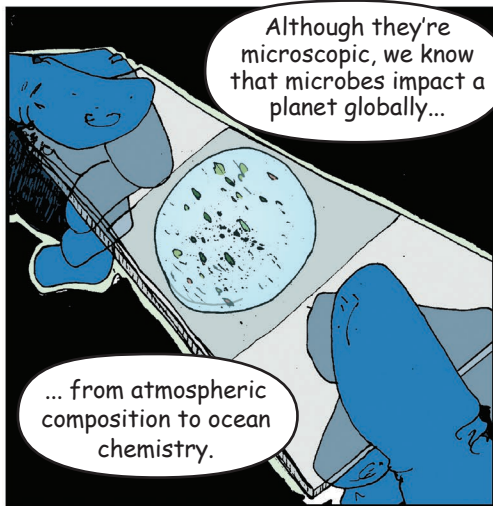
Eddie Schwieterman, University of California, Riverside



We're looking for chemical signs of life.

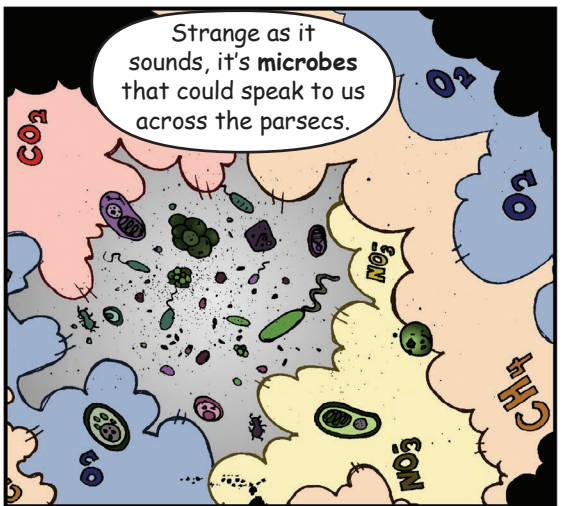
Gases created by biology, from microbes to plants, can alter the atmosphere.

The effect of primitive organisms like microbes might be the most likely thing we'll see.



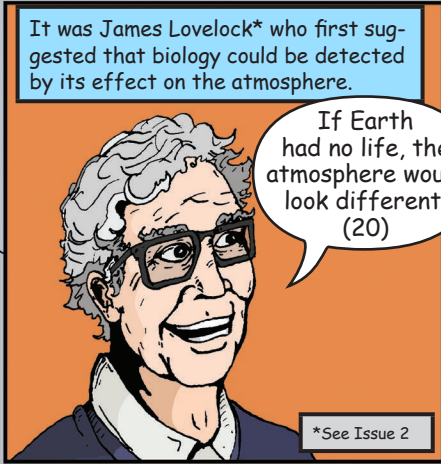
Although they're microscopic, we know that microbes impact a planet globally...

... from atmospheric composition to ocean chemistry.



Strange as it sounds, it's microbes that could speak to us across the parsecs.

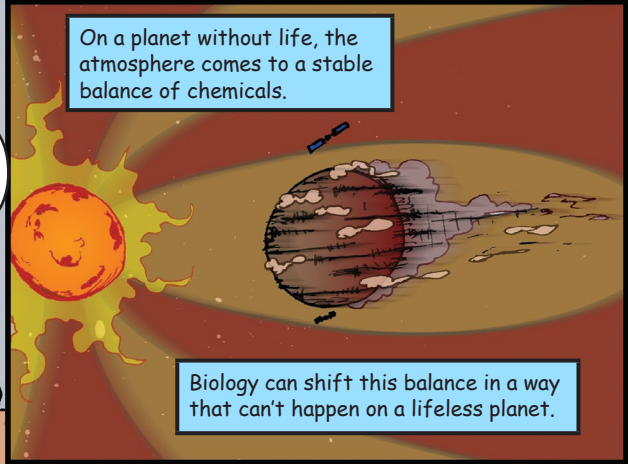
It was James Lovelock* who first suggested that biology could be detected by its effect on the atmosphere.



If Earth had no life, the atmosphere would look different. (20)

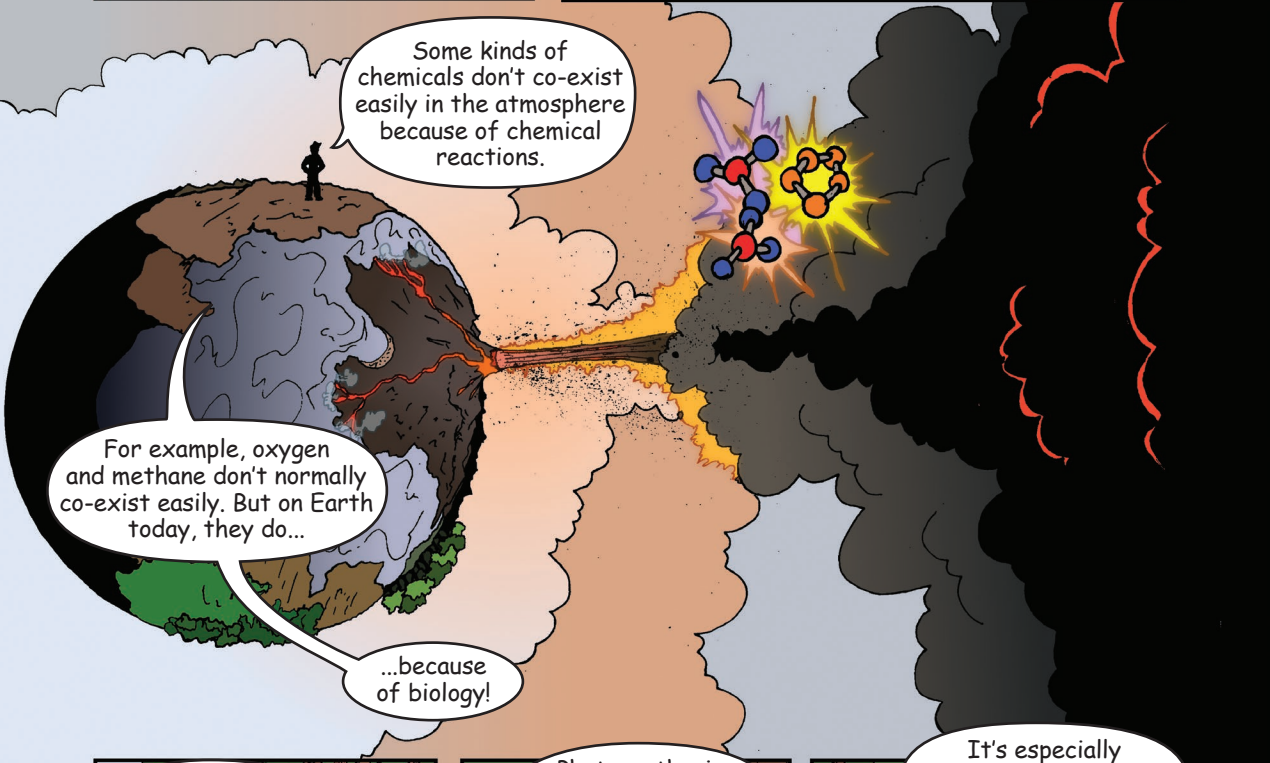
*See Issue 2

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

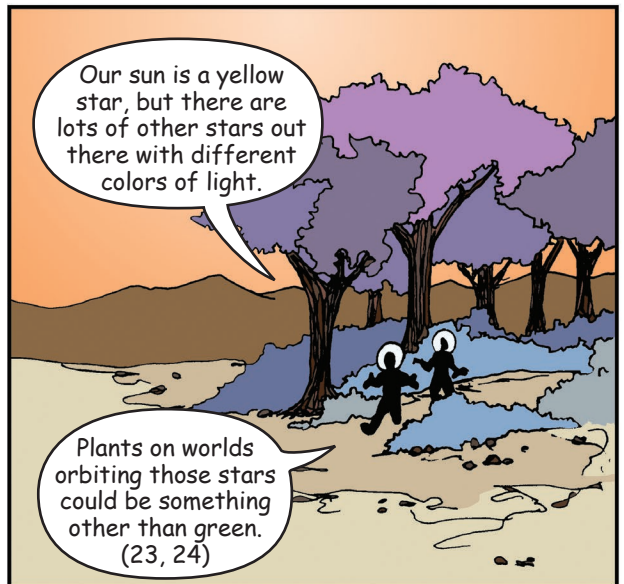
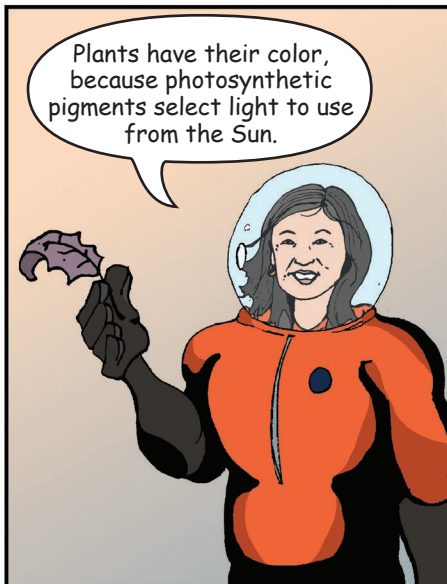
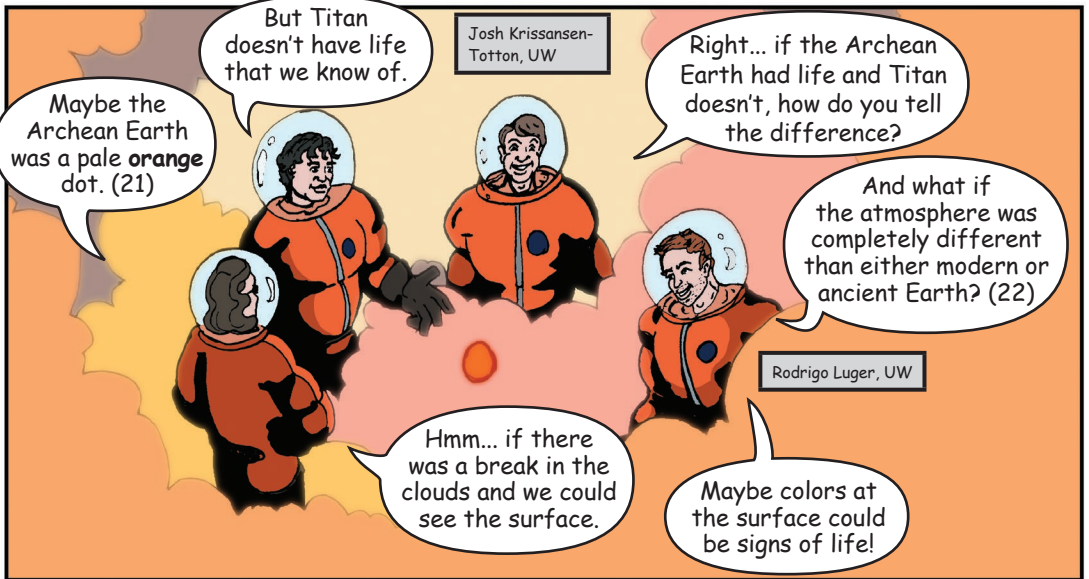
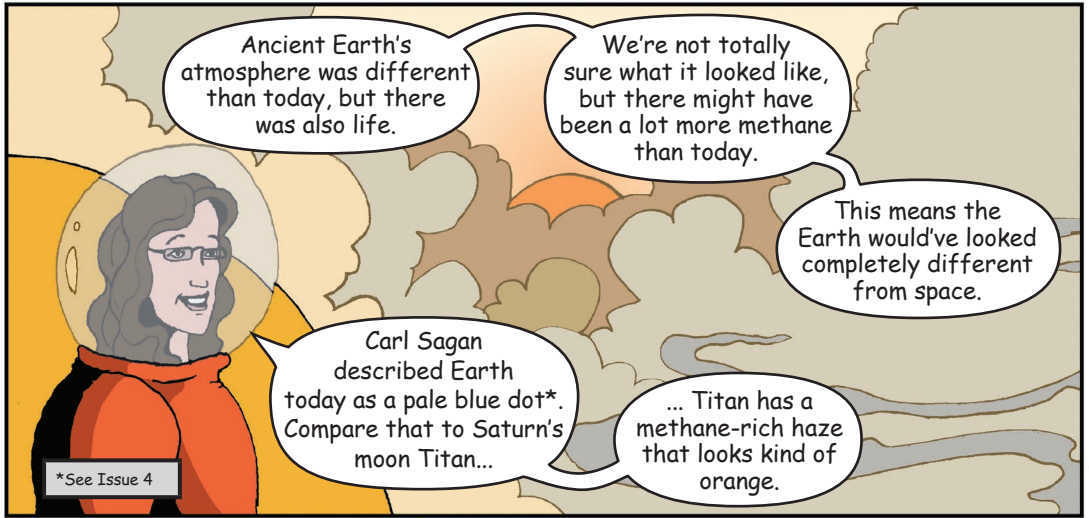
Photosynthesis makes the oxygen, and it also makes cool colors that can be seen from space!

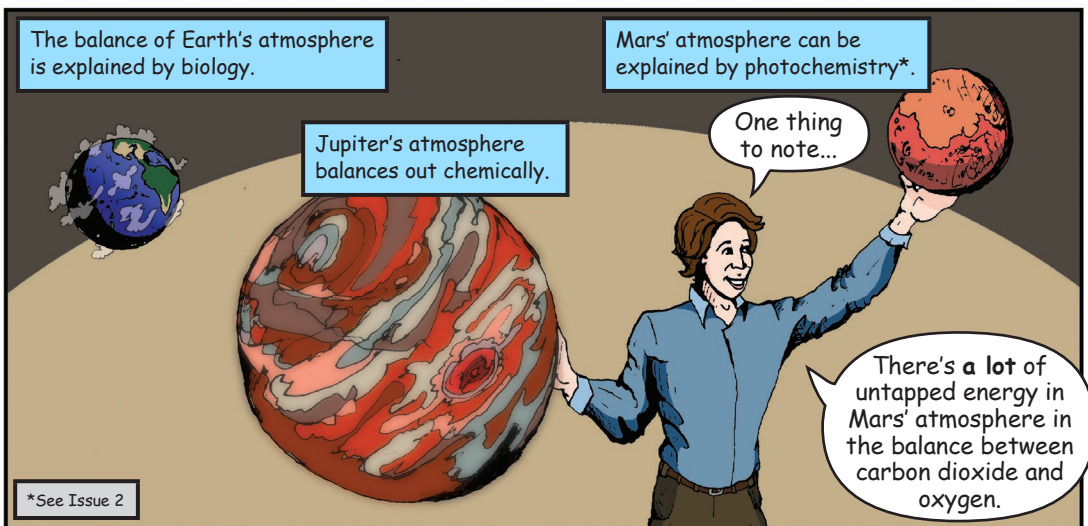
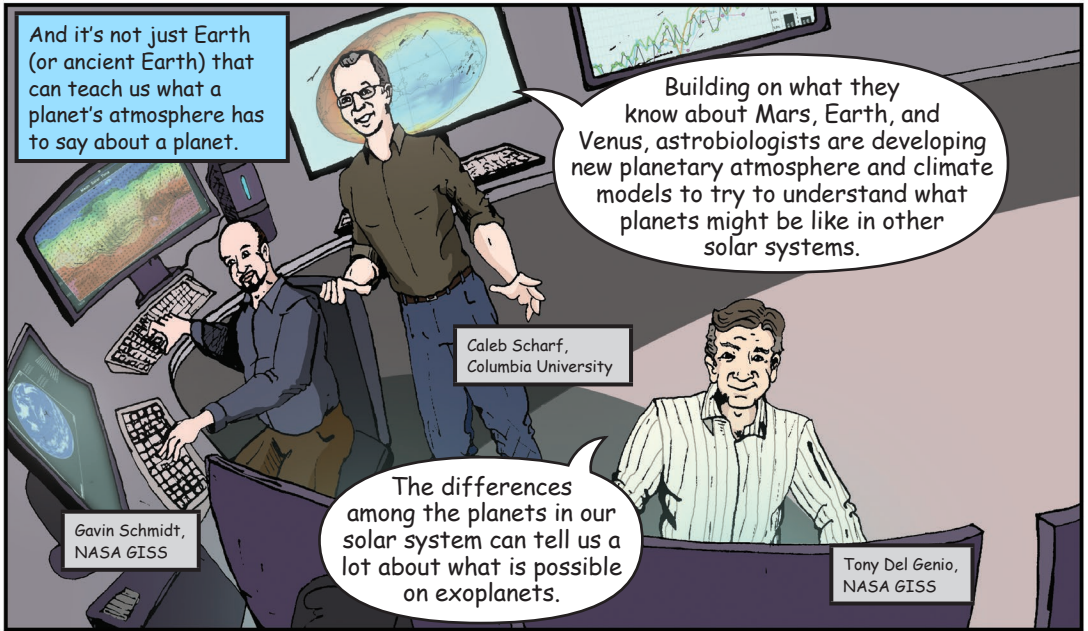
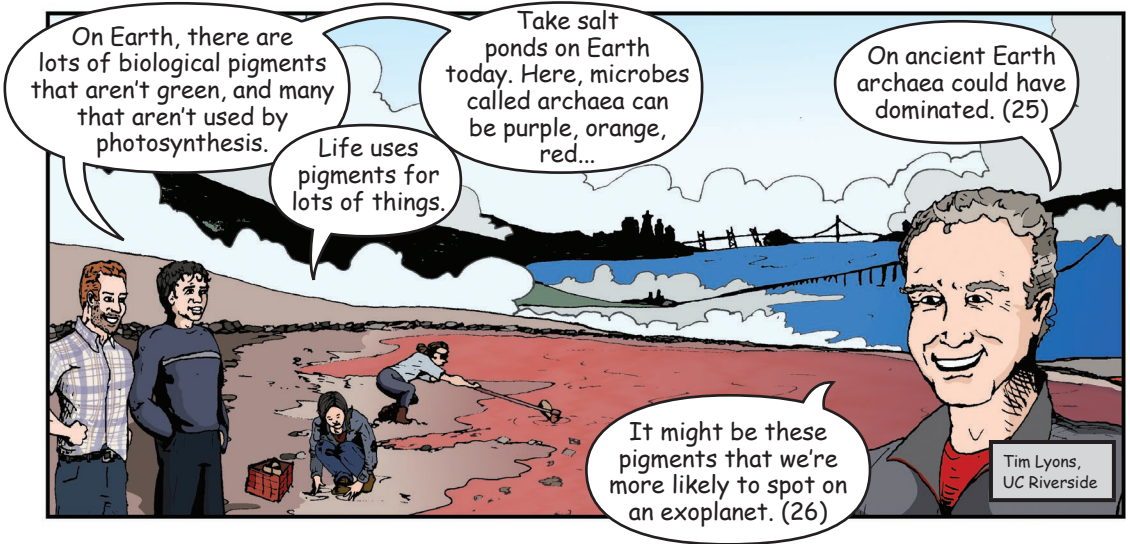


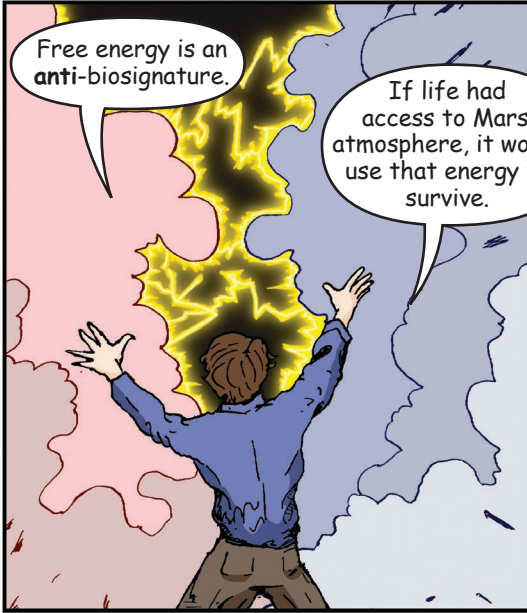
It's especially easy to see things like forests and grasslands covering the land.



Nancy Kiang, NASA GISS

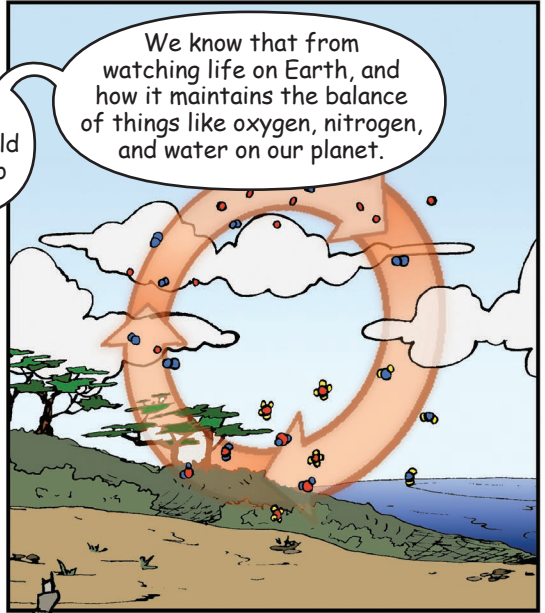




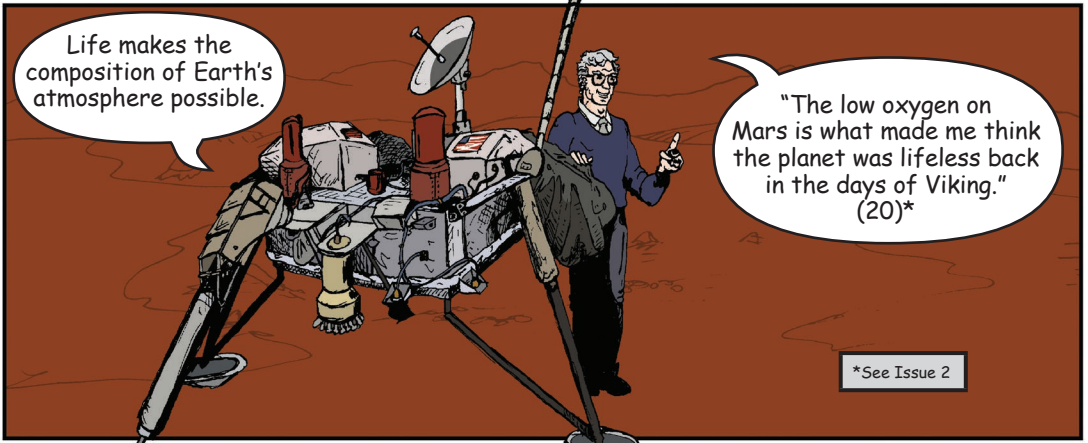


Free energy is an **anti-biosignature**.

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!...

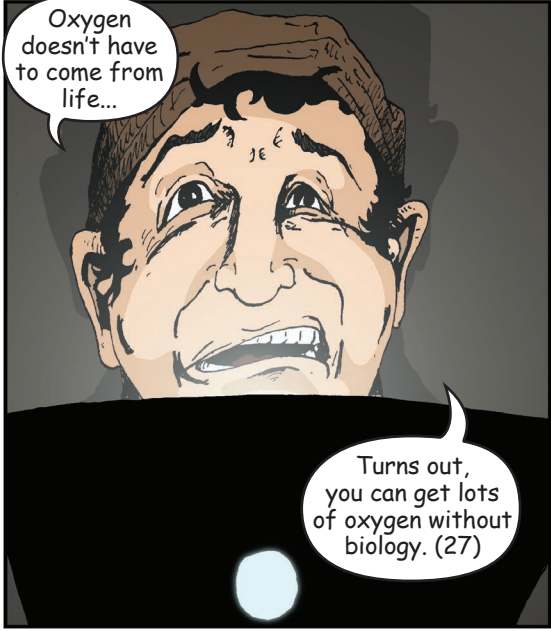


What, is something wrong?

Uh... yeah.
More coffee?

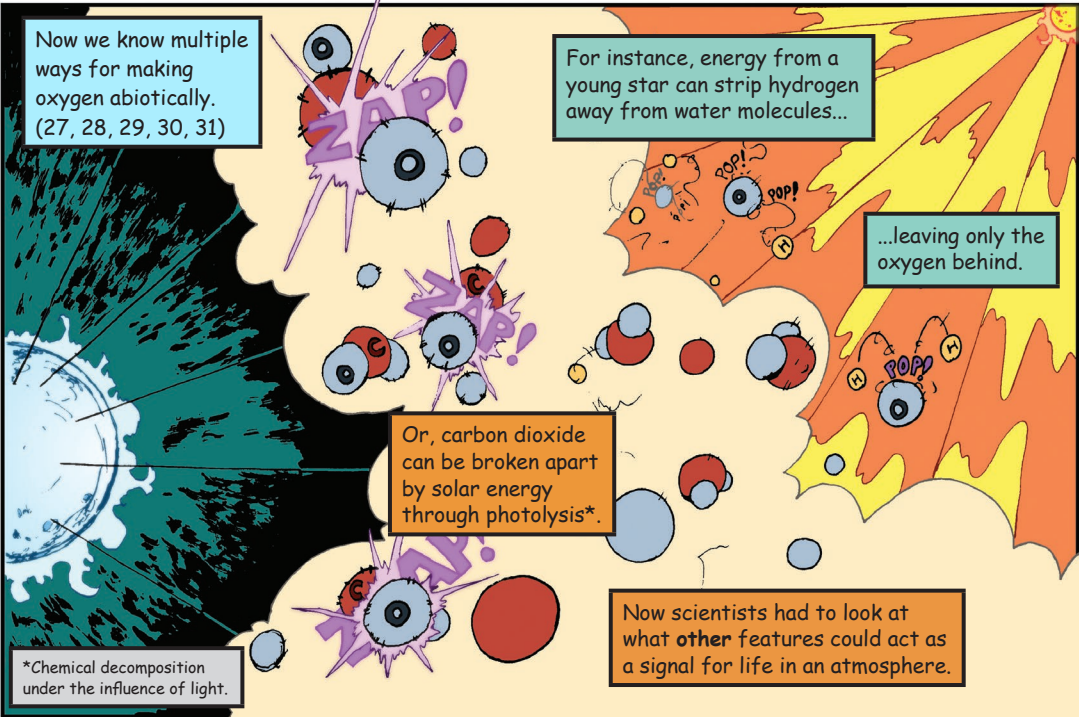
No, not that...

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)

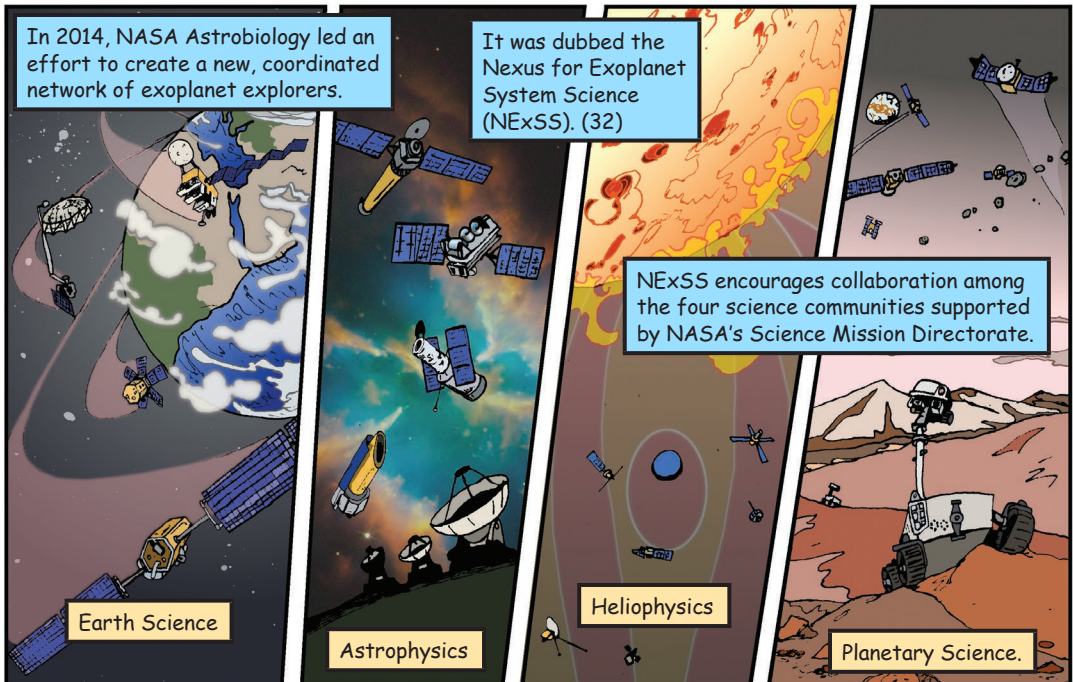
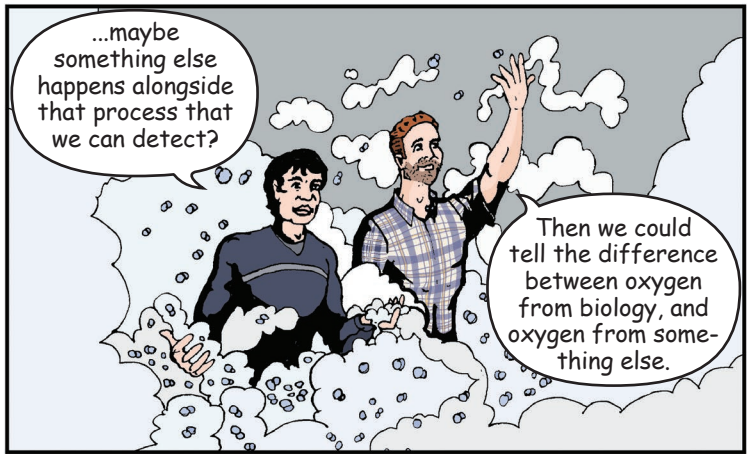
For instance, energy from a young star can strip hydrogen away from water molecules...

...leaving only the oxygen behind.

Or, carbon dioxide can be broken apart by solar energy through photolysis*

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.





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.

Steve Desch, Arizona State University

Eric Ford, Penn State

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.

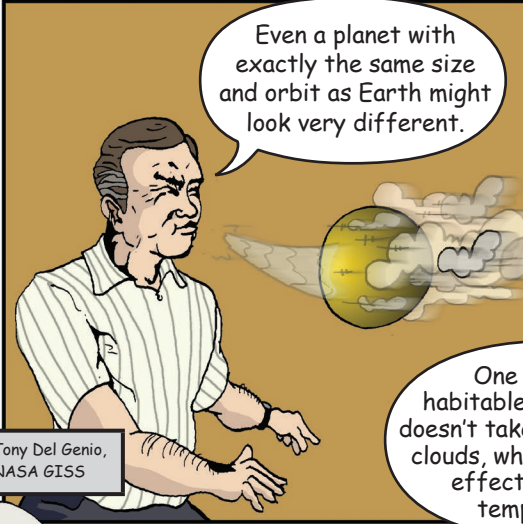
Earth sits in the middle.

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.

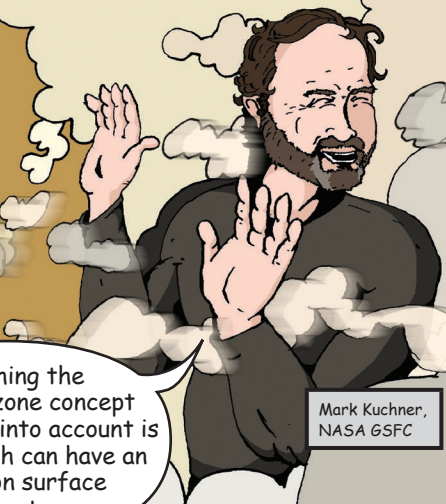
These findings indicate that we might find a terrestrial planet that theoretically sits in the habitable zone... yet isn't actually habitable.





Tony Del Genio, NASA GISS

Even a planet with exactly the same size and orbit as Earth might look very different.



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.

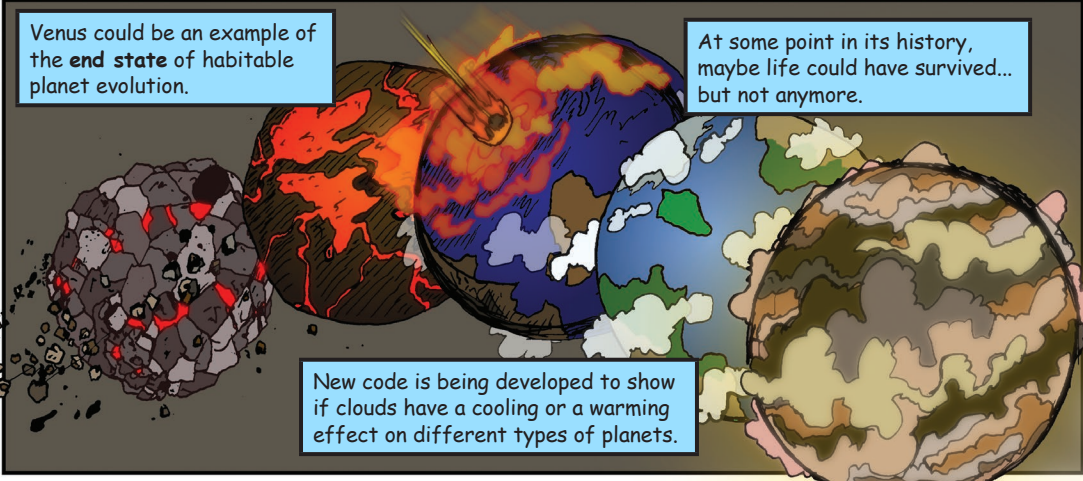
Venus might have been habitable long ago, if it had clouds like Earth's that kept a lot of sunlight out. But today, carbon dioxide in Venus' atmosphere causes a greenhouse effect that makes the planet way too hot for life*.



* See Issue 3

Whew!

Maybe ancient Venus was habitable... but now it might be an example of what the future holds for Earth*.



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 characterize basic properties like planet colors.*

*See page 16

There are other things to consider about the habitable zone.

Russell Deitrick, UW

Rory Barnes, UW

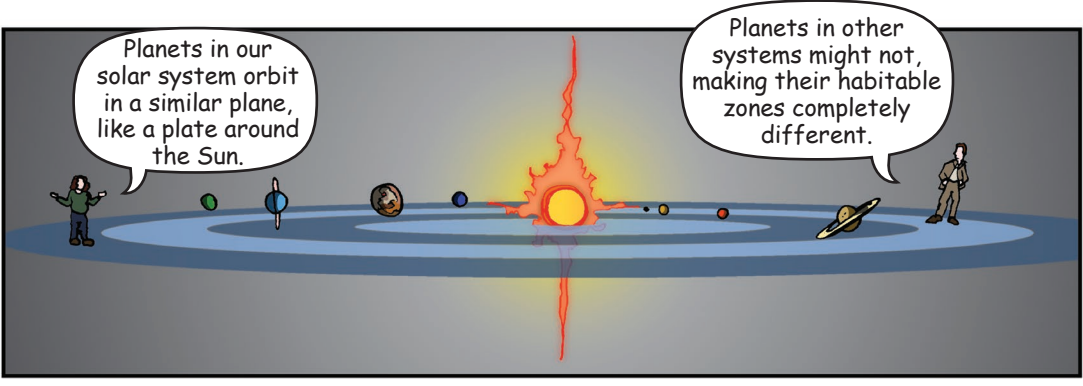
Yeah, there is a lot more to habitability than a planet's distance from its star.

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)

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.

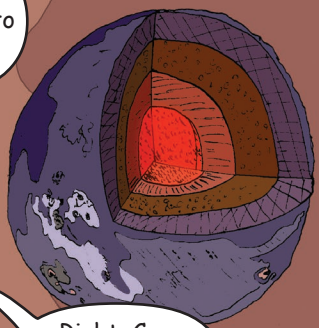
If the orbit isn't circular, a planet could cook part of the time... and freeze for the other part! (40, 41)

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)

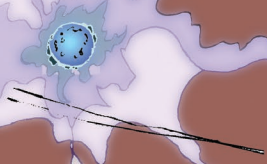
Or a star with a lot of flares?

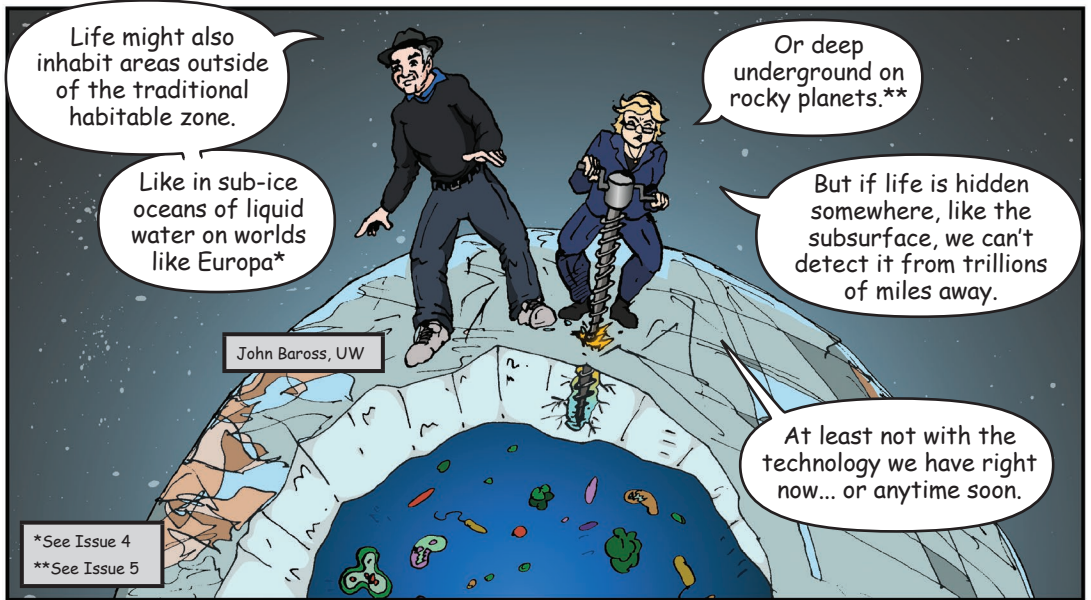
Like a red dwarf? (43)

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*

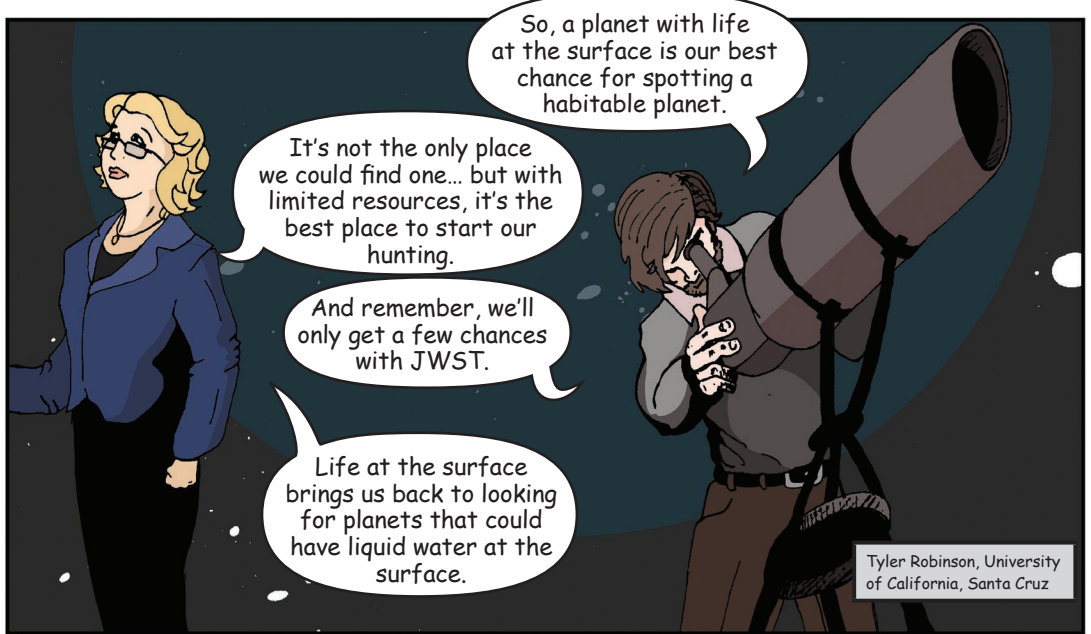
Or deep underground on rocky planets.**

But if life is hidden somewhere, like the subsurface, we can't detect it from trillions of miles away.

John Baross, UW

At least not with the technology we have right now... or anytime soon.

*See Issue 4
**See Issue 5



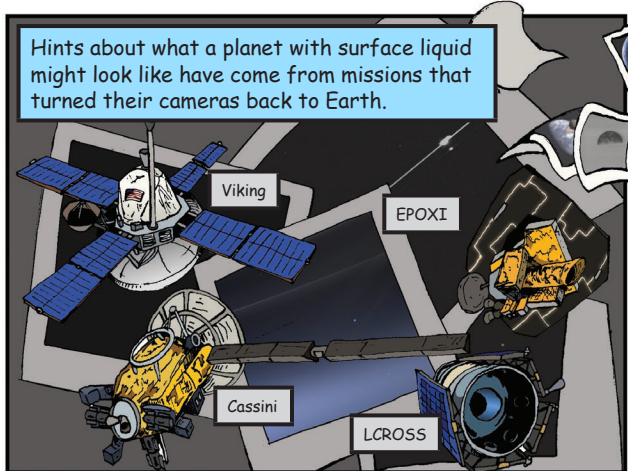
So, a planet with life at the surface is our best chance for spotting a habitable planet.

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



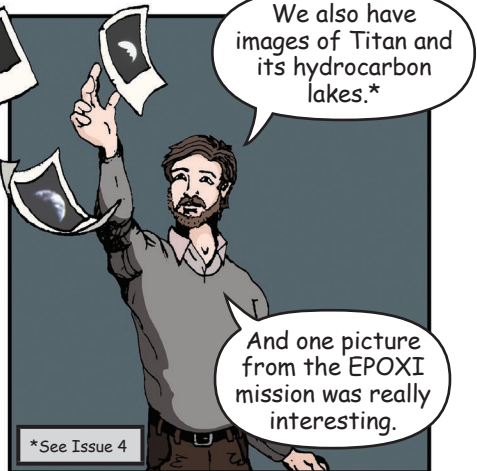
Hints about what a planet with surface liquid might look like have come from missions that turned their cameras back to Earth.

Viking

EPOXI

Cassini

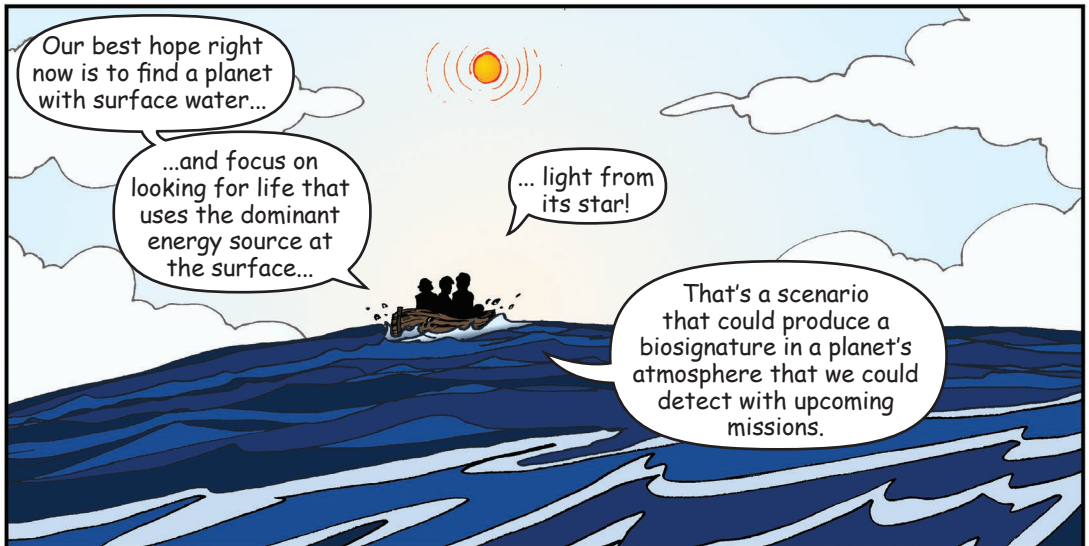
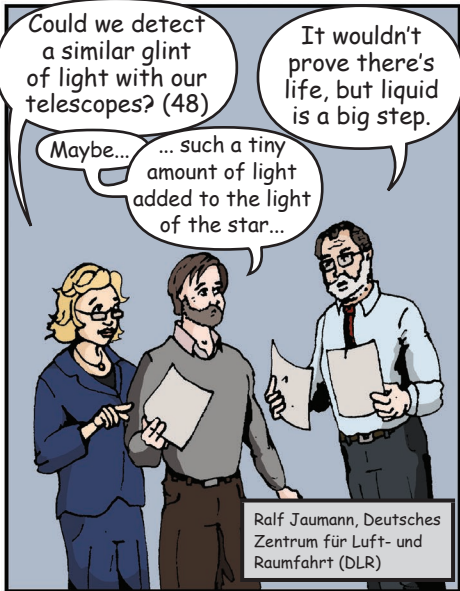
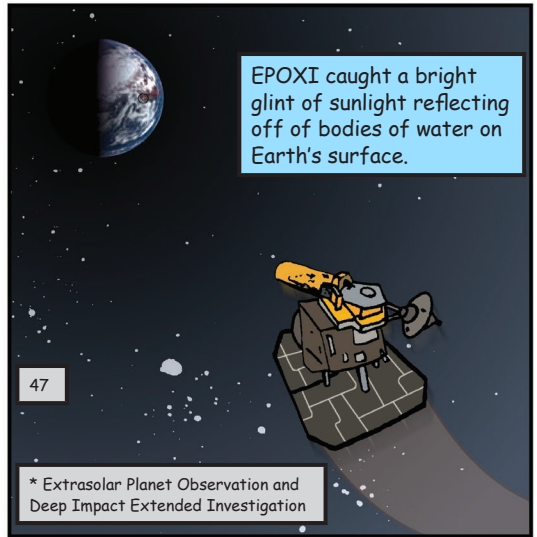
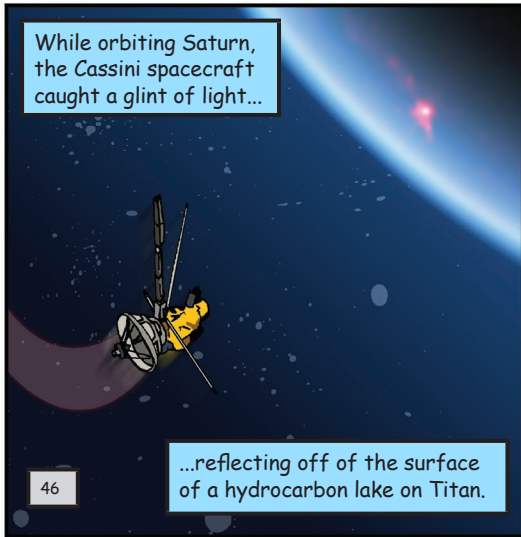
LCROSS



We also have images of Titan and its hydrocarbon lakes.*

And one picture from the EPOXI mission was really interesting.

*See Issue 4



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.

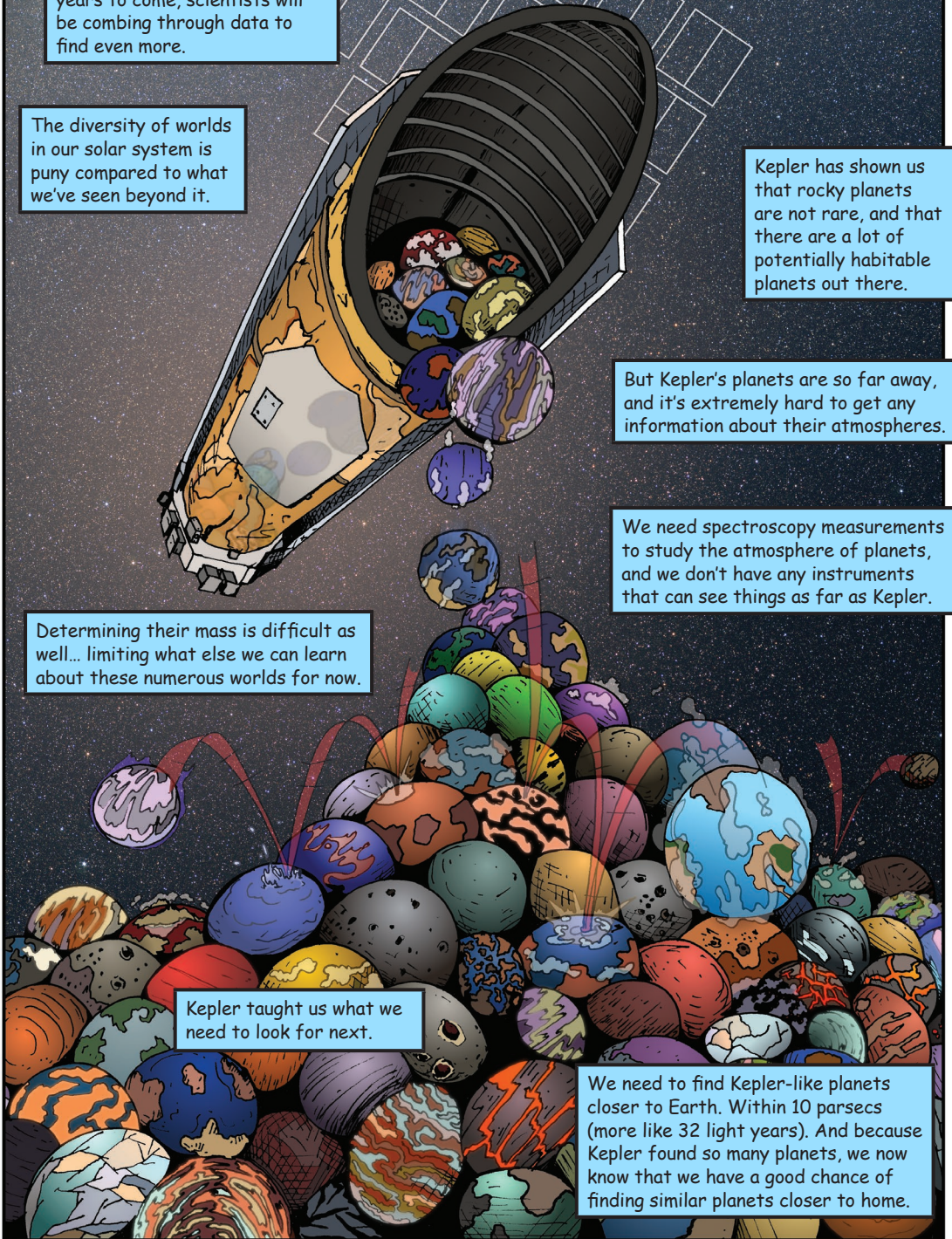
But Kepler's planets are so far away, and it's extremely hard to get any information about their atmospheres.

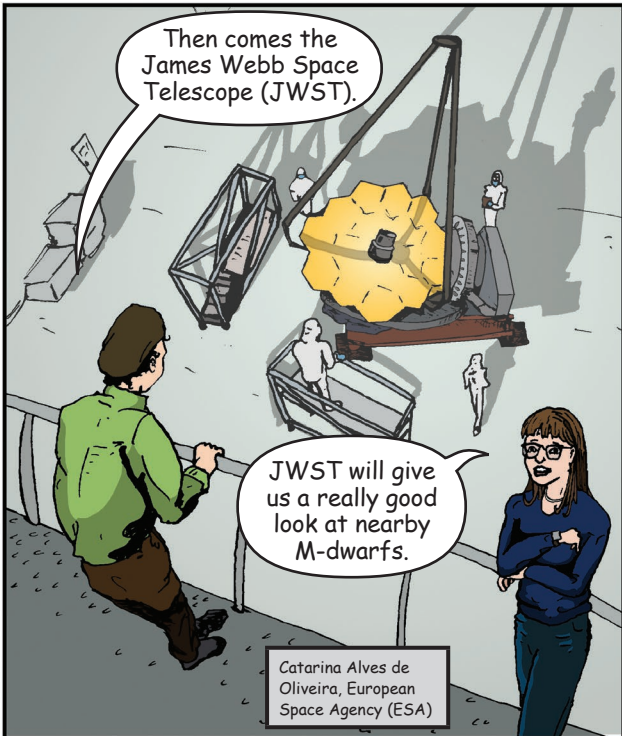
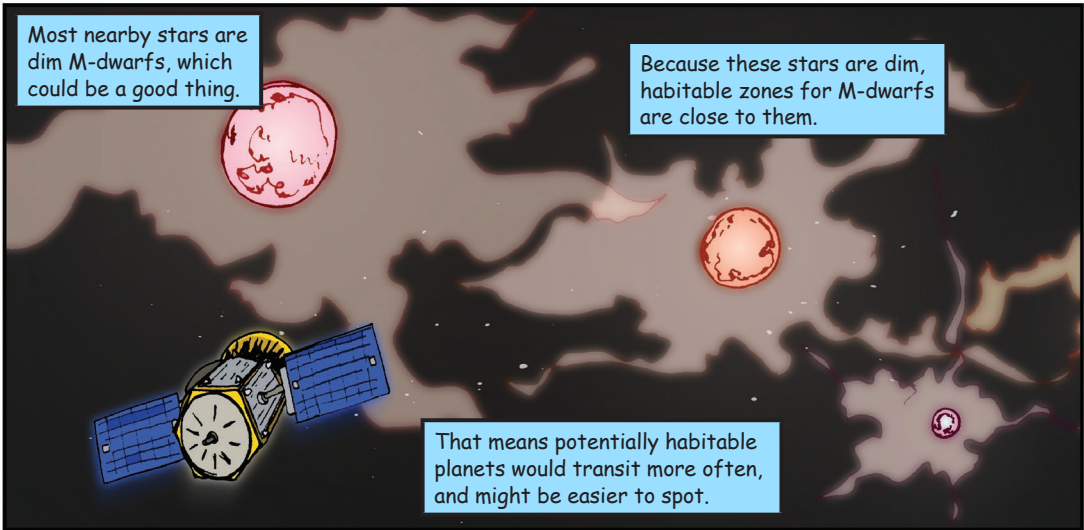
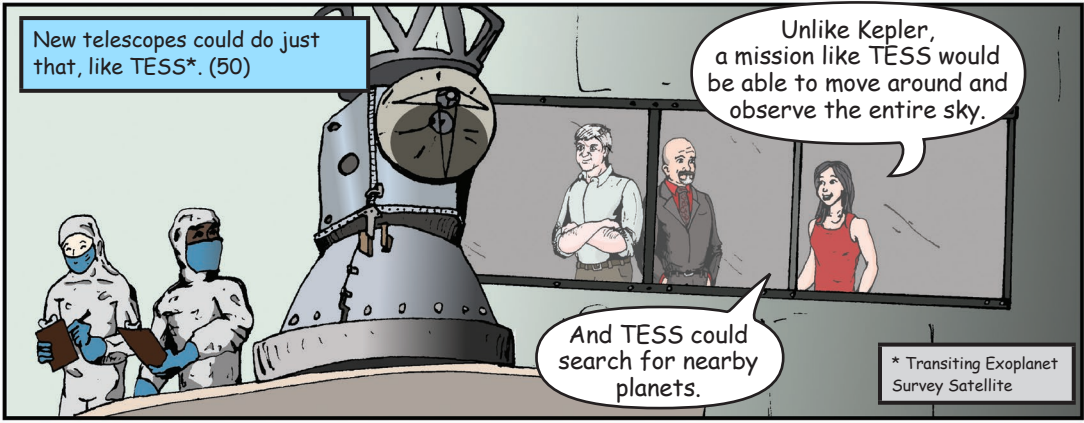
We need spectroscopy measurements to study the atmosphere of planets, and we don't have any instruments that can see things as far as Kepler.

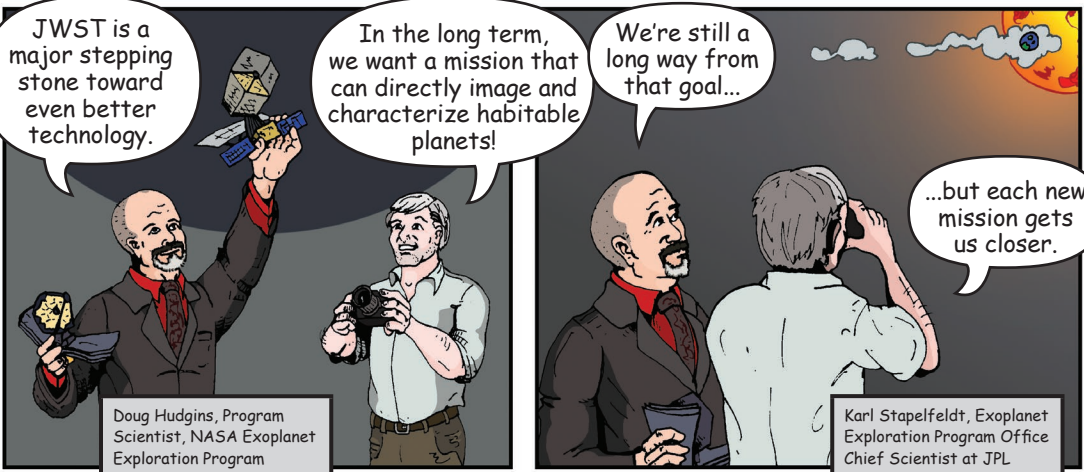
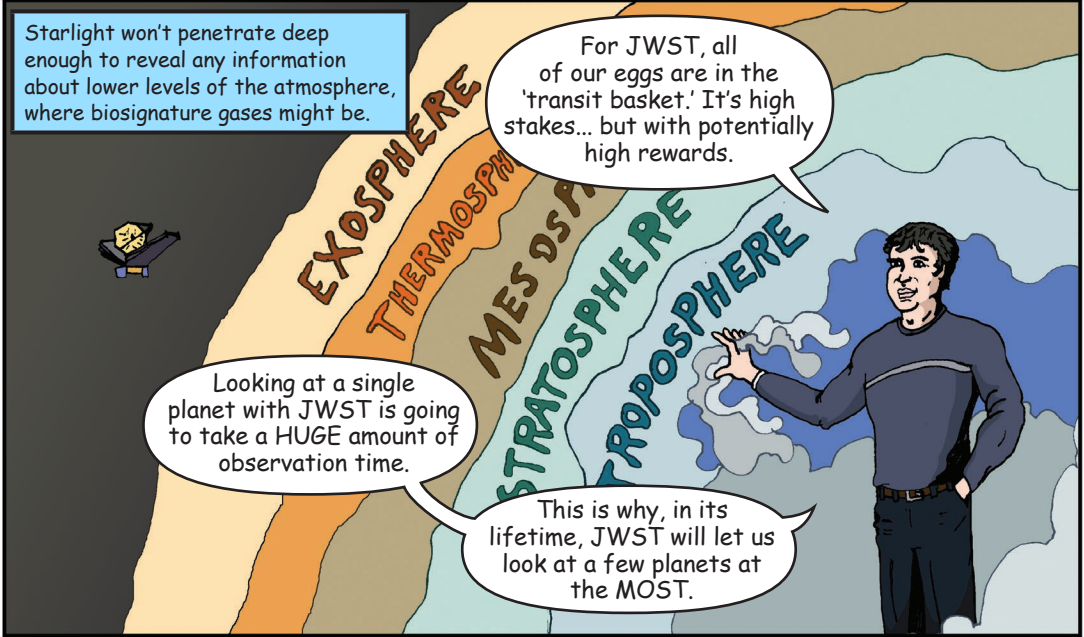
Determining their mass is difficult as well... limiting what else we can learn about these numerous worlds for now.

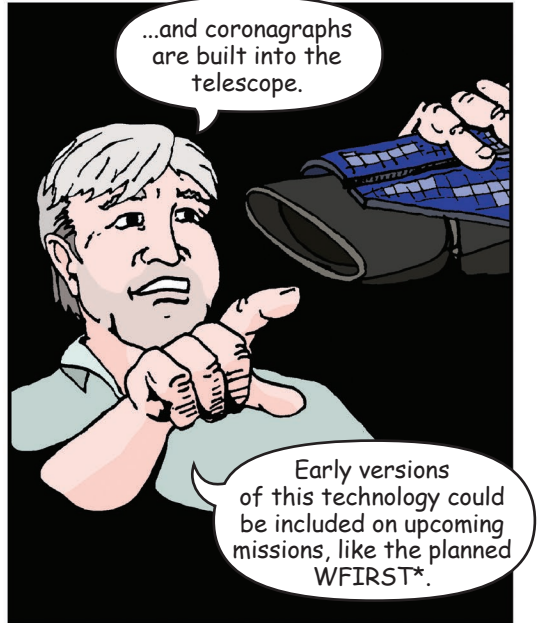
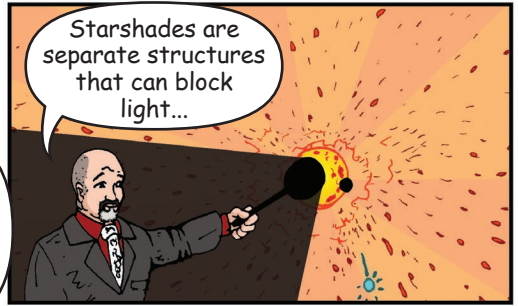
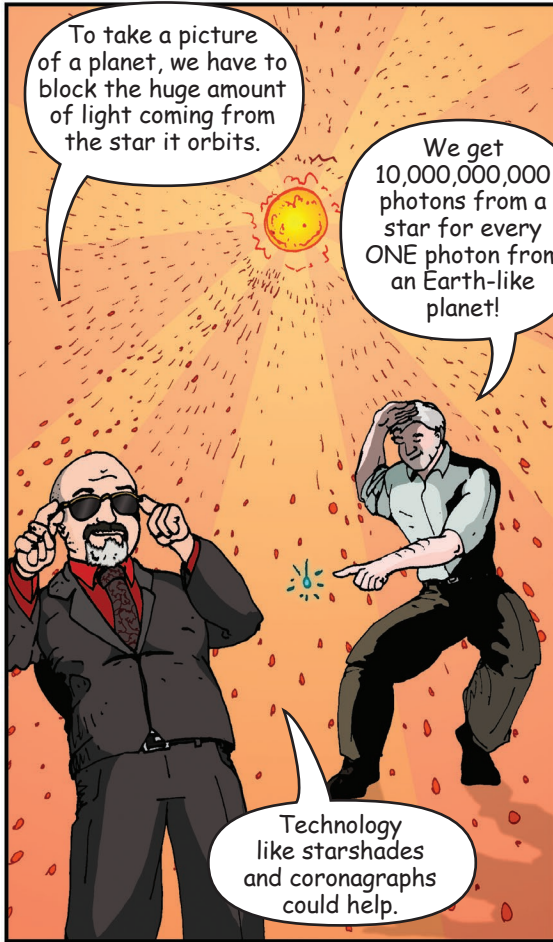
Kepler taught us what we need to look for next.

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.

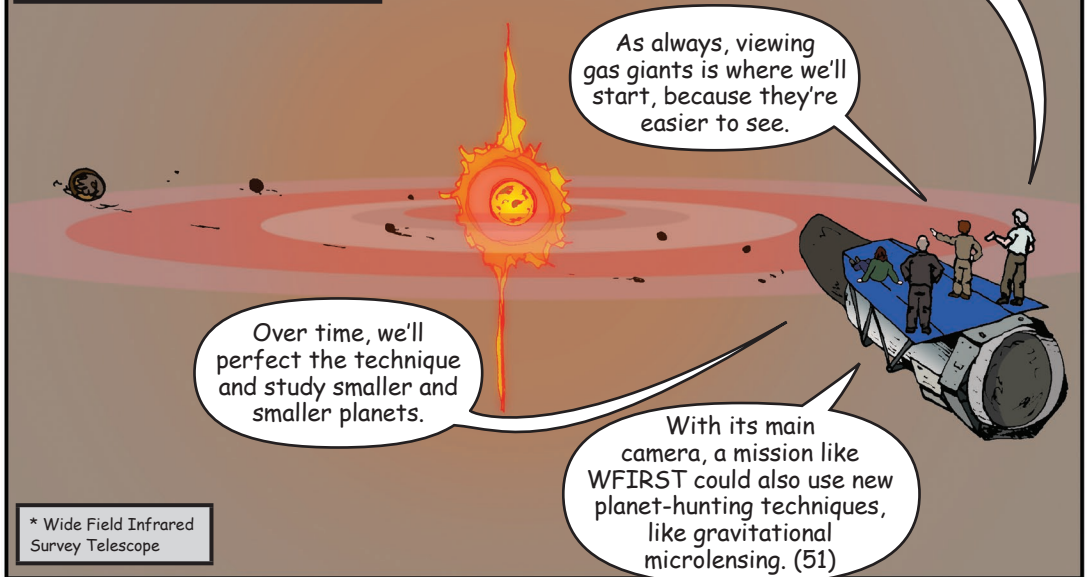




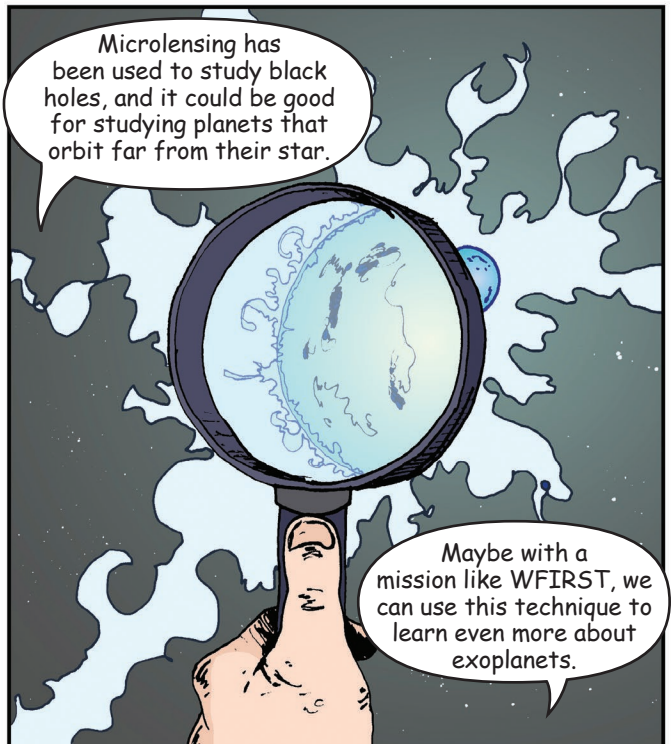
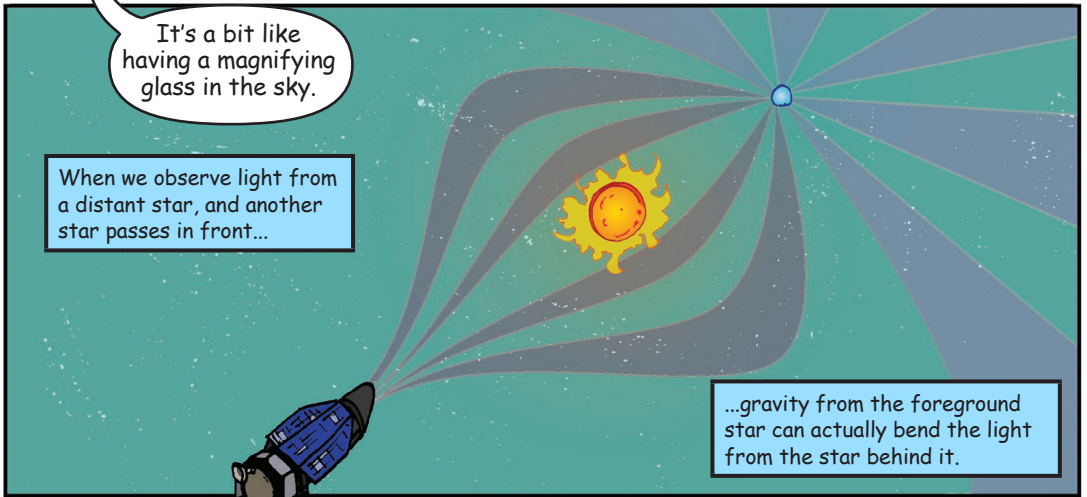
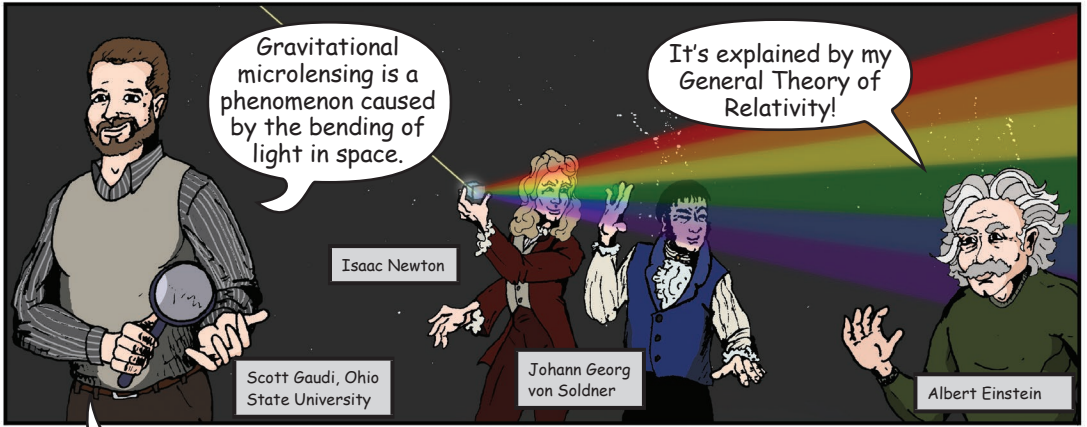


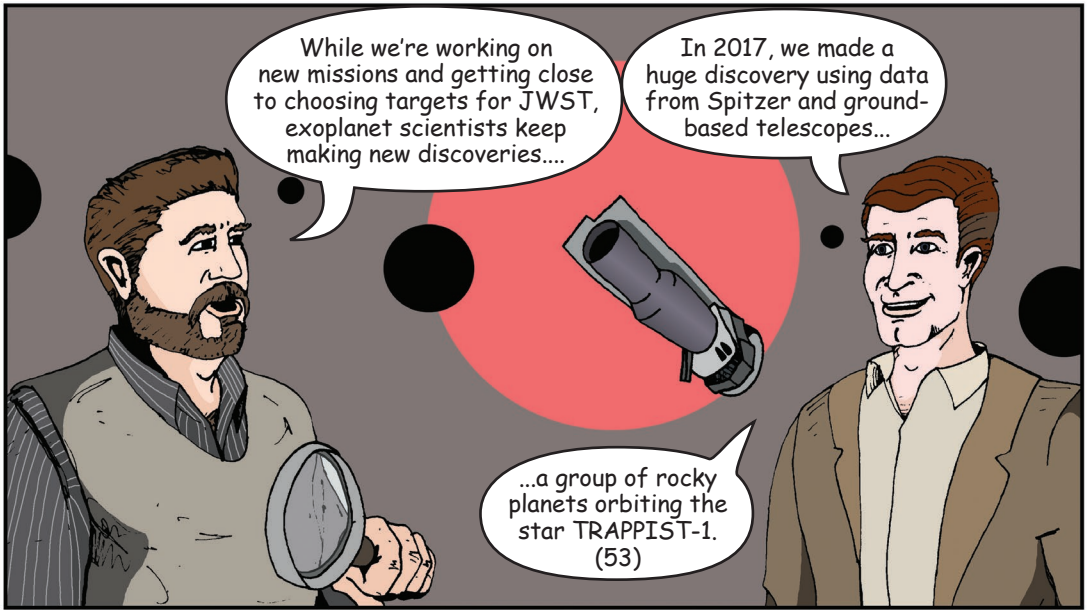


WFIRST could make observations in the near-infrared (NIR) part of the spectrum. Its main camera would take images that are 100 times larger than those of the Hubble Space Telescope. (51)



* Wide Field Infrared Survey Telescope

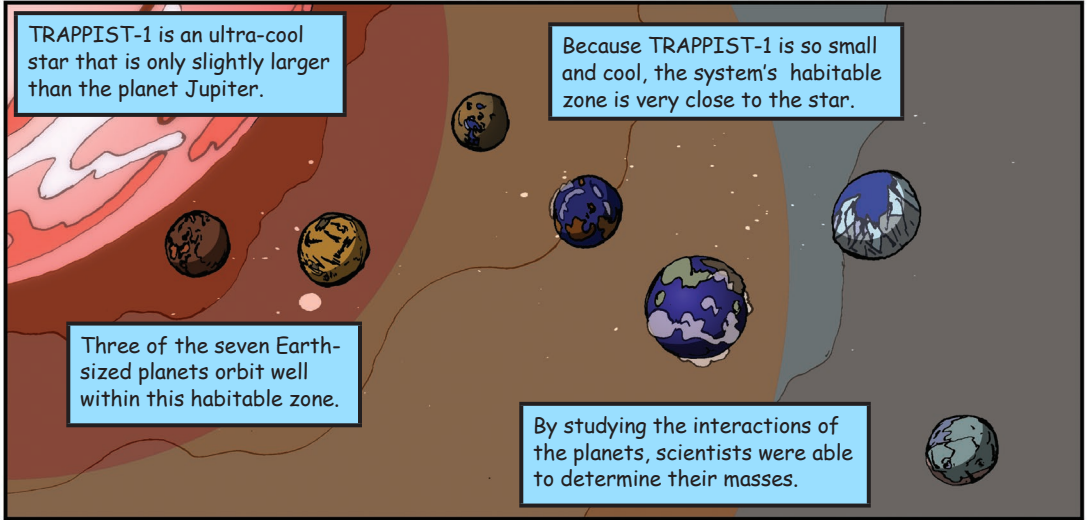




While we're working on new missions and getting close to choosing targets for JWST, exoplanet scientists keep making new discoveries....

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)

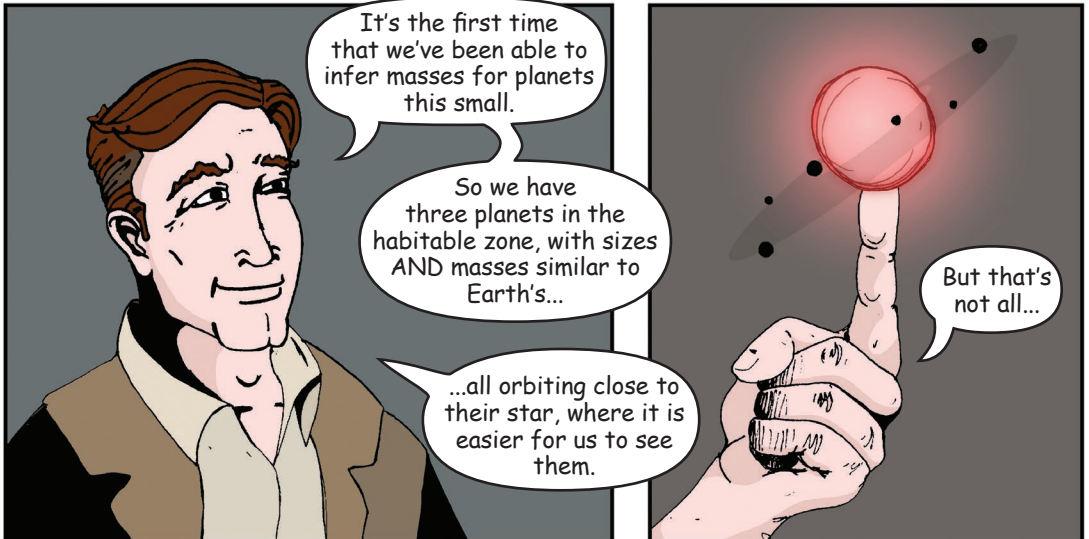


TRAPPIST-1 is an ultra-cool star that is only slightly larger than the planet Jupiter.

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.

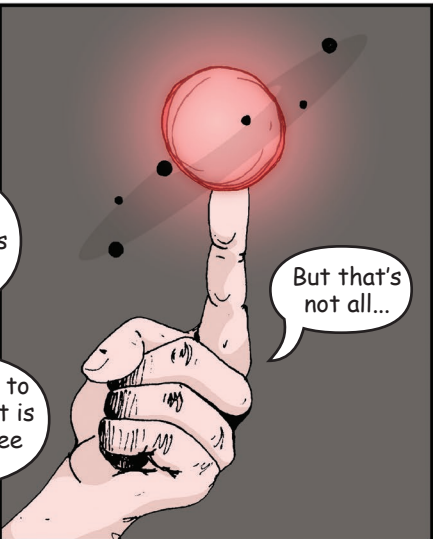
By studying the interactions of the planets, scientists were able to determine their masses.



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)

Right! We might actually be able to study their atmospheres with telescopes we have TODAY.

Aki Roberge, NASA GSFC

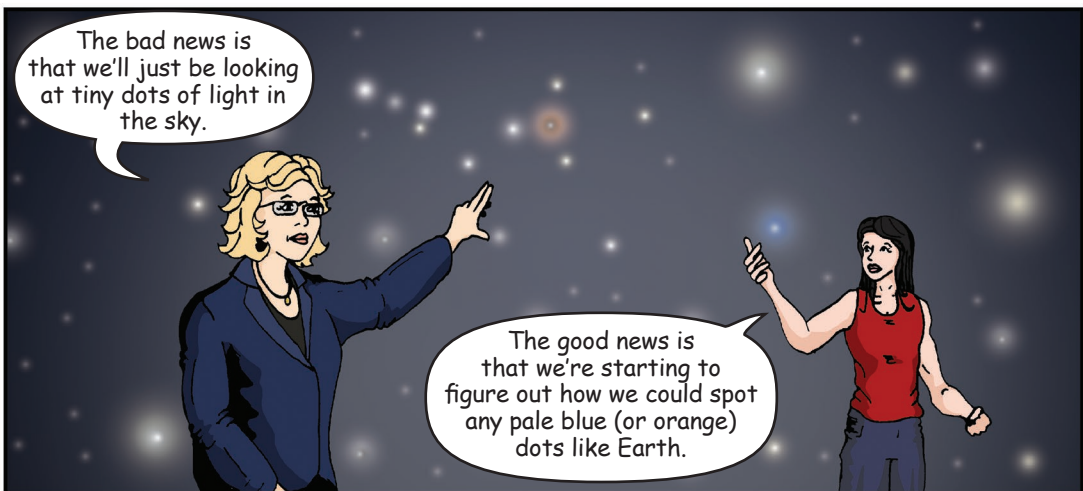
And, of course, they could be great candidates for the technology we're building right now.

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.

But right now, we have only a handful of chances to spot an exoplanet with life.

Biospheres, much like planets, might be more diverse than we ever imagined.

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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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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