National Aeronautics and Space Administration

Issue #4

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.

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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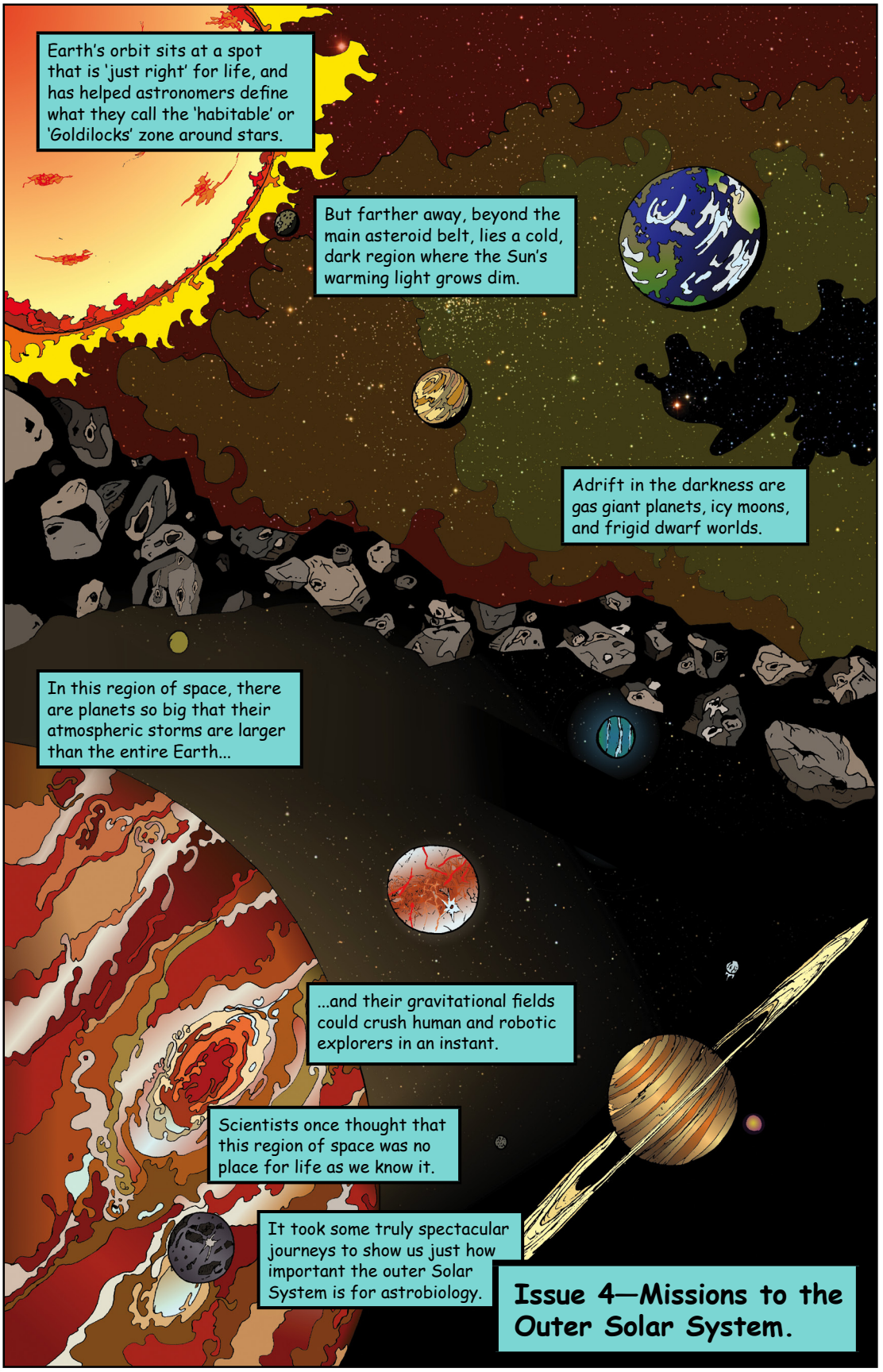
Issue #4
Missions to the Outer Solar System

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 fourth 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's orbit sits at a spot that is 'just right' for life, and has helped astronomers define what they call the 'habitable' or 'Goldilocks' zone around stars.
But farther away, beyond the main asteroid belt, lies a cold, dark region where the Sun's warming light grows dim.
Adrift in the darkness are gas giant planets, icy moons, and frigid dwarf worlds.
In this region of space, there are planets so big that their atmospheric storms are larger than the entire Earth...
...and their gravitational fields could crush human and robotic explorers in an instant.
Scientists once thought that this region of space was no place for life as we know it.
It took some truly spectacular journeys to show us just how important the outer Solar System is for astrobiology.
Issue 4—Missions to the Outer Solar System.


The giant planets of the outer Solar System have fascinated humans for a long time. (1)
They are very far away, but Jupiter and Saturn are so giant that they shine brightly in the night sky.
When Galileo Galilei spotted Jupiter's moons,* it occurred to him that the Universe might not be centered on the Earth. (2)
Hmm...
"...the Sun remains fixed in the centre of the circle of heavenly bodies, without changing its place..." (3)
By the time the space age dawned, scientists like Harold Urey* began to wonder what planetary moons were made of.
"The interiors of objects of similar mass [to the Earth's moon]... must have risen above the melting point of ice in their interiors..."
"Hence the water of the Jovian moons must all be at or near their surfaces!"
"In fact, water flows, instead of terrestrial lava flows, may occur from time to time." (4)
To truly understand the outer Solar System, astrobiologists needed close-up views that only space missions could provide.
*see Issue #1
In 1965, NASA scientist Gary Flandro realized that the planets were in a rare position relative to one another—an event that only occurred every 175 years! (5,6)
I have and idea.
What if we used Jupiter's powerful gravity as a slingshot?
A spacecraft could use the energy to visit all the giant planets in one 'Grand Tour!'
NASA'S SOLAR JAM!
SPACESHIP IN PLAY!
NASA was ready for a game of interplanetary pinball!

It took a lot of hard work both scientifically and politically to get the first missions off the ground...

...but in 1972, the Pioneer 10 spacecraft launched. It was followed by Pioneer 11.

"After [Pioneer 10] passed Mars on its long journey into deep space, it was venturing into places where nothing built by humanity had ever gone before." (7)

It took seven months for Pioneer 10 to make the 435 million-kilometer trek through the asteroid belt, proving the journey was possible. (8)

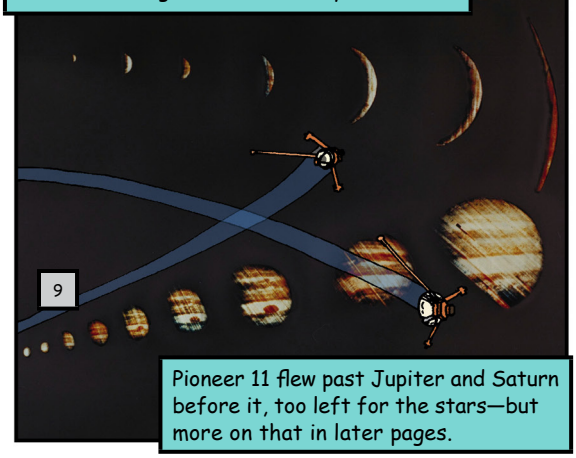
"We are really only twelve generations away from Galileo and his first crude look at [Jupiter]. Twelve generations later we are actually there, measuring many of the characteristics of the planet itself." (2)

Colleen Hartman, Deputy Director for Science, Operations and Program Performance at NASA Goddard.

Charles F. Hall, Pioneer Project Manager

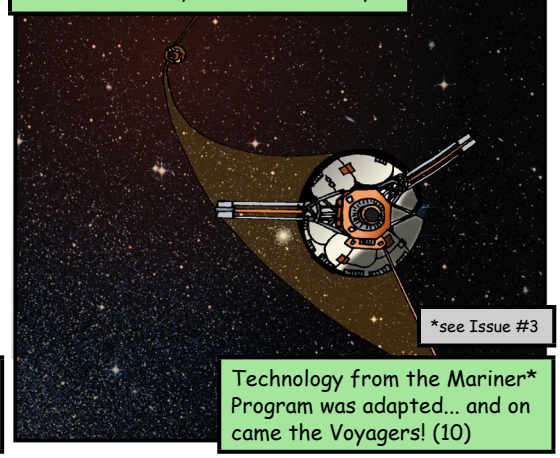
Pioneer was a 'flyby' mission, meaning both spacecraft flew past the giant planets and their moons rather than orbiting them.

Pioneer 10 visited Jupiter and then flew out toward the edge of the Solar System.



Pioneer 11 flew past Jupiter and Saturn before it, too left for the stars—but more on that in later pages.

With knowledge gained from Pioneer, NASA was ready for the next step.



*see Issue #3

Technology from the Mariner* Program was adapted... and on came the Voyagers! (10)

Like Pioneer, the twin Voyager spacecraft were designed for planetary flybys. But they were even more powerful than their predecessors.

Voyager 1 arrived at Jupiter on March 5, 1979. Voyager 2 followed later that year on July 9.

Voyager 1 visited Jupiter and Saturn, while Voyager 2 collected data from Jupiter, Saturn, Uranus and Neptune!

Thanks to the relative positions of the planets, the flight time to Neptune was reduced from thirty years to just twelve! (see page 3).

As a planet, Jupiter was obviously no place for life as we know it...

...but watching phenomena like clouds on the gas giant has helped scientists better understand physical processes here on Earth.

Studying Jupiter also provided clues about the origin and evolution of giant planets around distant stars.

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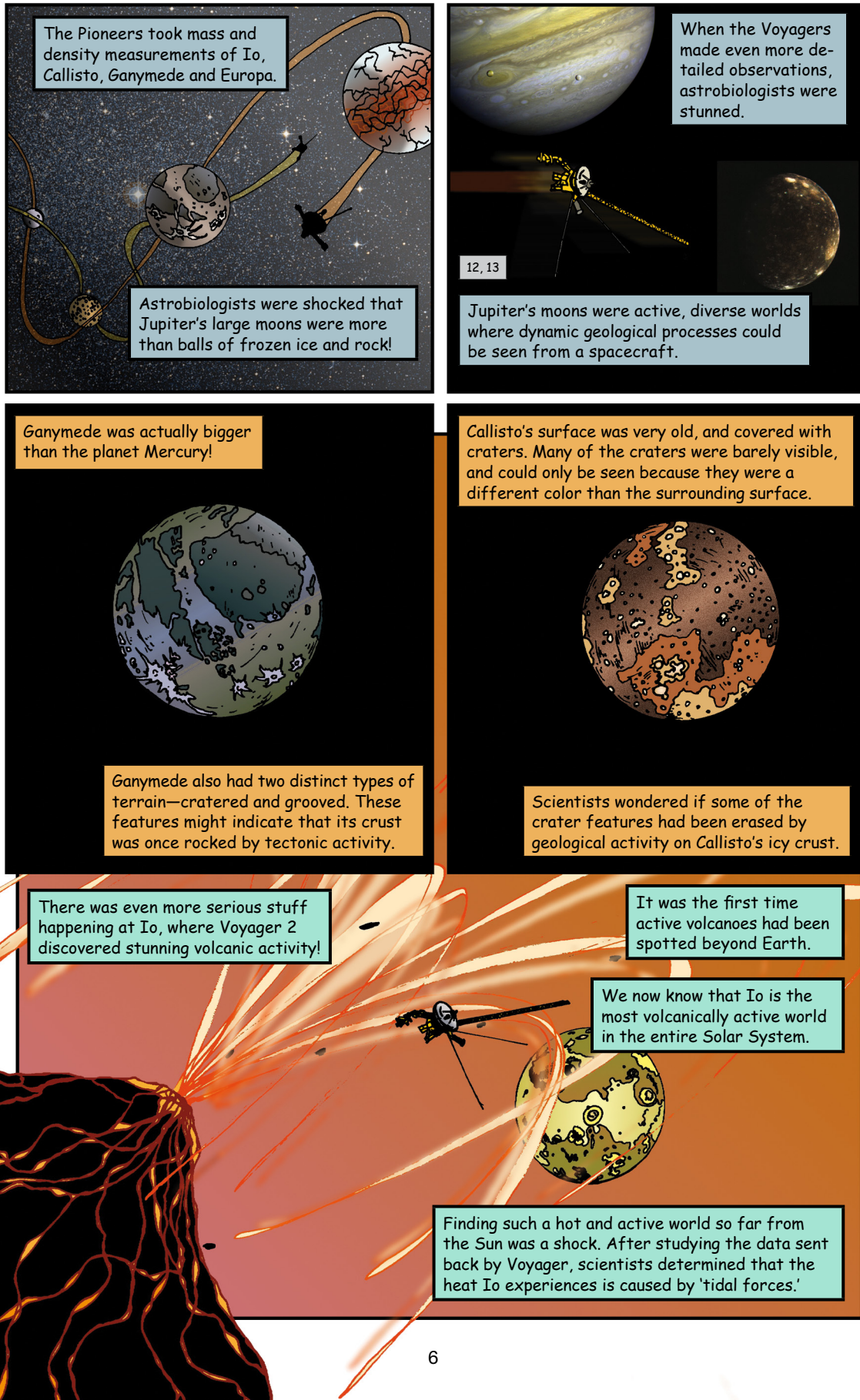
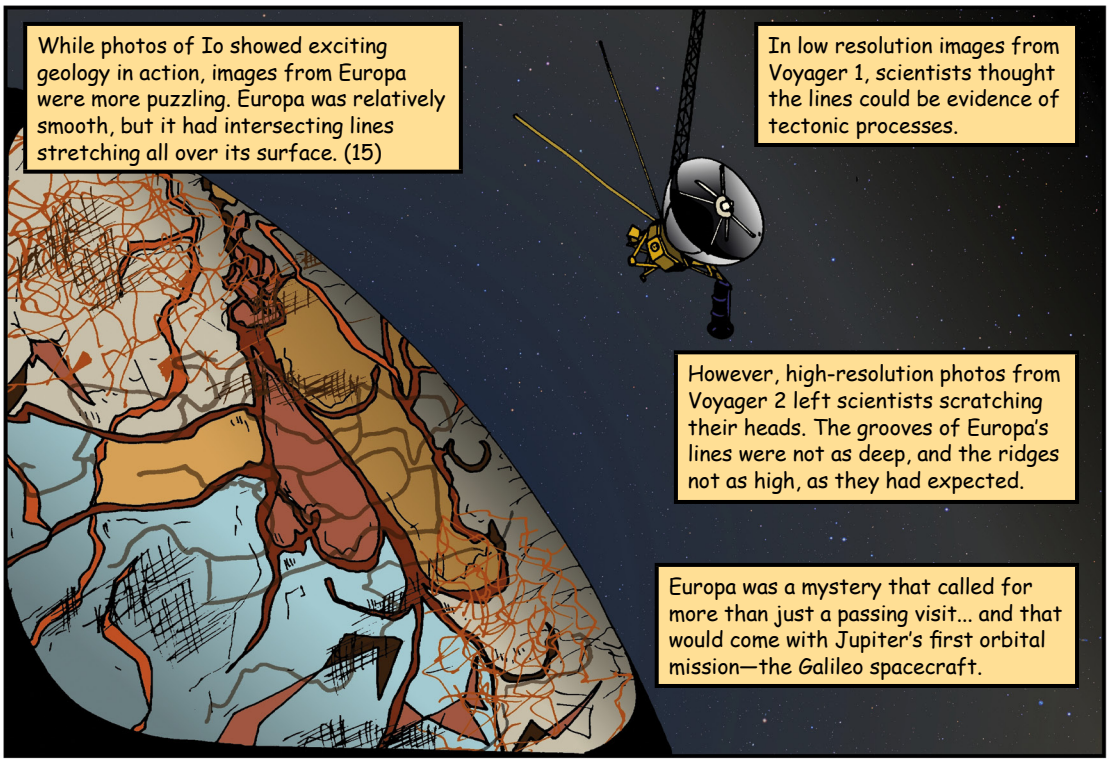
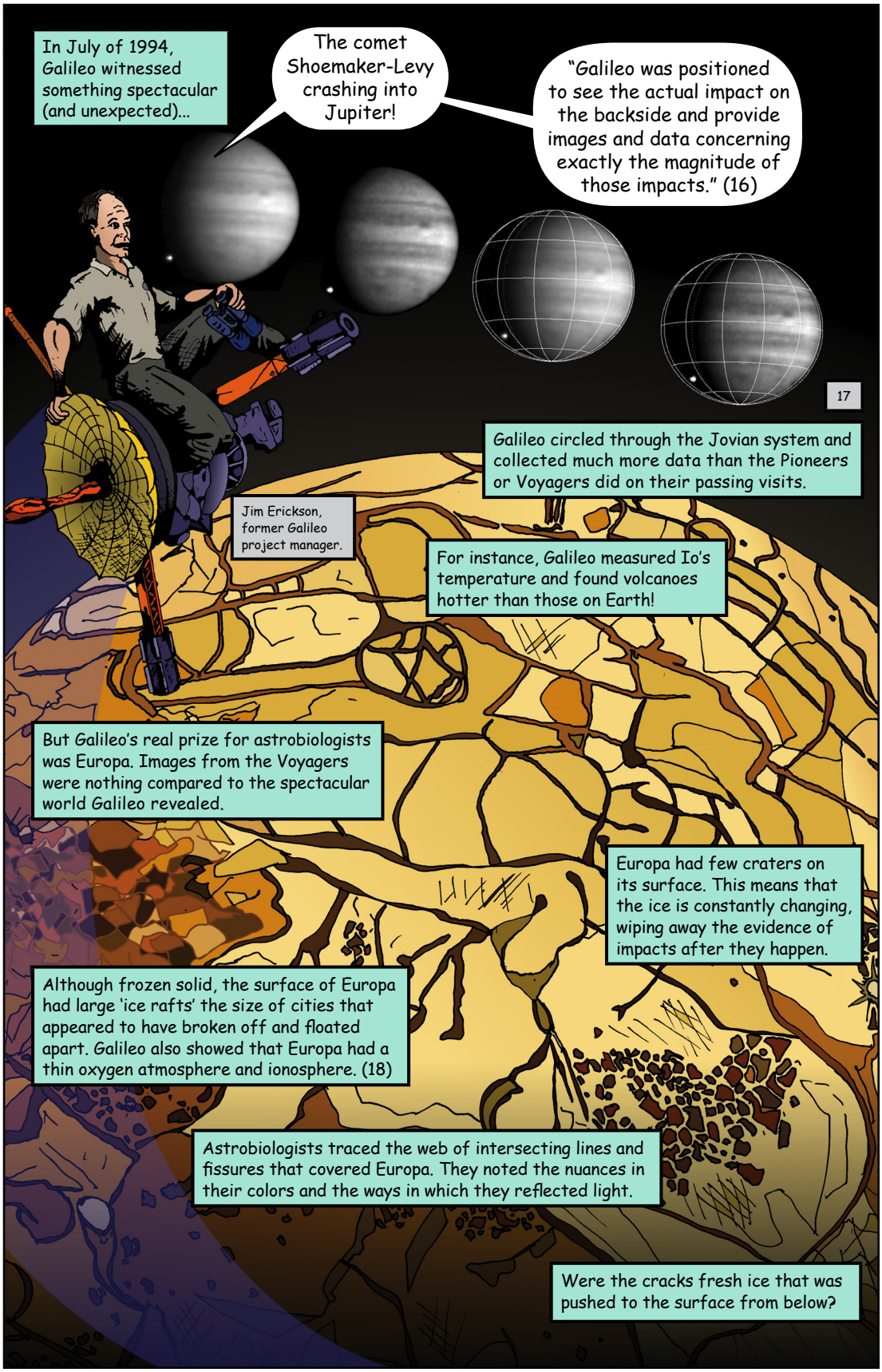
But for astrobiologists, the real prizes of Pioneer and Voyager observations were Jupiter's moons!


The Pioneers took mass and density measurements of Io, Callisto, Ganymede and Europa.
Astrobiologists were shocked that Jupiter's large moons were more than balls of frozen ice and rock!
When the Voyagers made even more detailed observations, astrobiologists were stunned.
12, 13
Jupiter's moons were active, diverse worlds where dynamic geological processes could be seen from a spacecraft.
Ganymede was actually bigger than the planet Mercury!
Ganymede also had two distinct types of terrain—cratered and grooved. These features might indicate that its crust was once rocked by tectonic activity.
Callisto's surface was very old, and covered with craters. Many of the craters were barely visible, and could only be seen because they were a different color than the surrounding surface.
Scientists wondered if some of the crater features had been erased by geological activity on Callisto's icy crust.
There was even more serious stuff happening at Io, where Voyager 2 discovered stunning volcanic activity!
It was the first time active volcanoes had been spotted beyond Earth.
We now know that Io is the most volcanically active world in the entire Solar System.
Finding such a hot and active world so far from the Sun was a shock. After studying the data sent back by Voyager, scientists determined that the heat Io experiences is caused by 'tidal forces.'

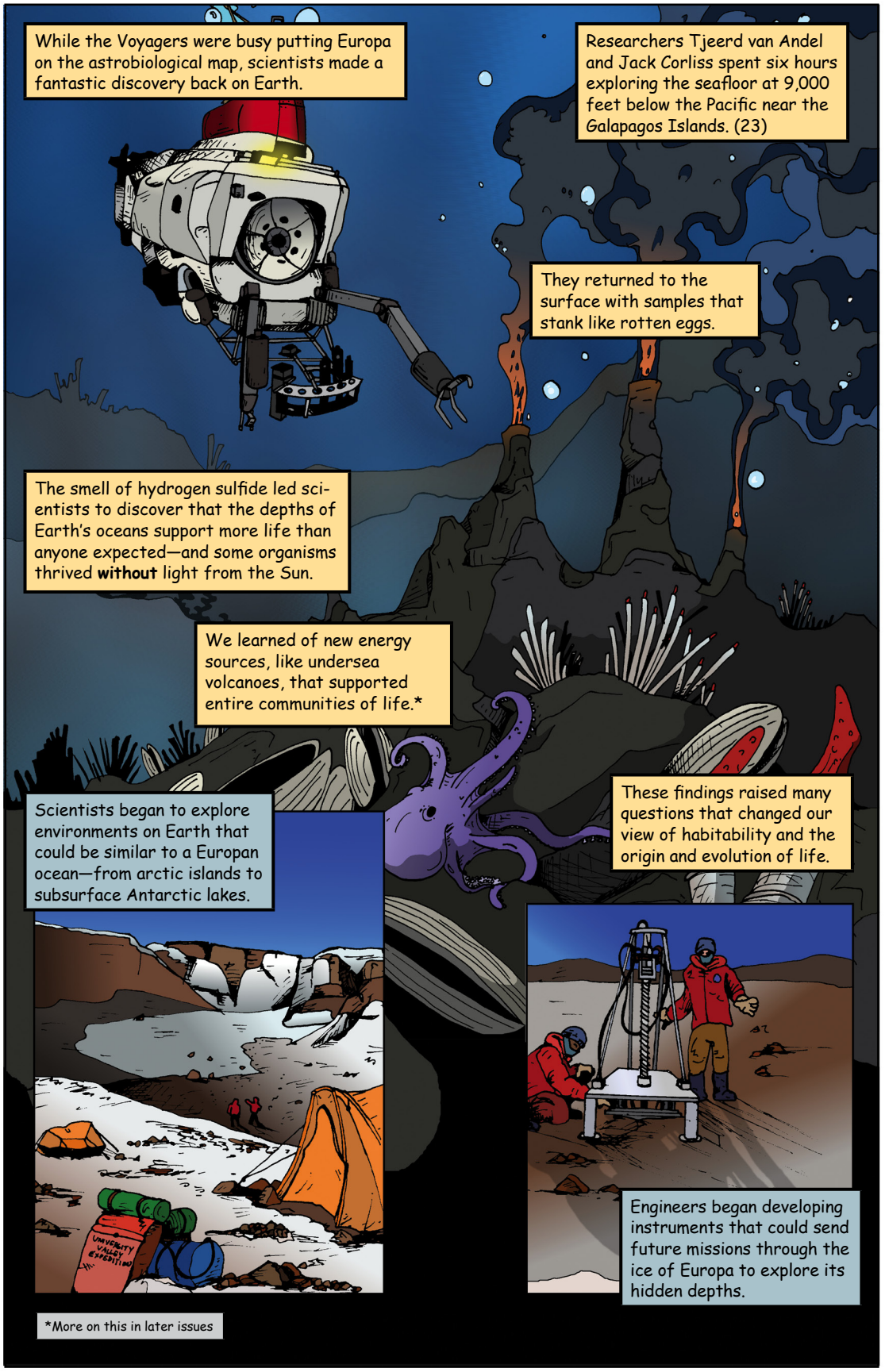

Io's orbit is affected by the nearby moons of Europa and Ganymede. Their gravity fields tug on Io whenever they come close.
After the moons move apart, Jupiter's massive gravity pulls Io back into line.
This gravitational 'tug-of-war' causes 'tidal bulging' of up to 100 meters (330 feet) on Io's surface. (14)
The 'squishing' and 'releasing' is what heats up the moon.
Tidal heating of Io raised questions about whether or not the same process could provide a source of heat and energy on other moons that lie far from the warmth of the Sun.

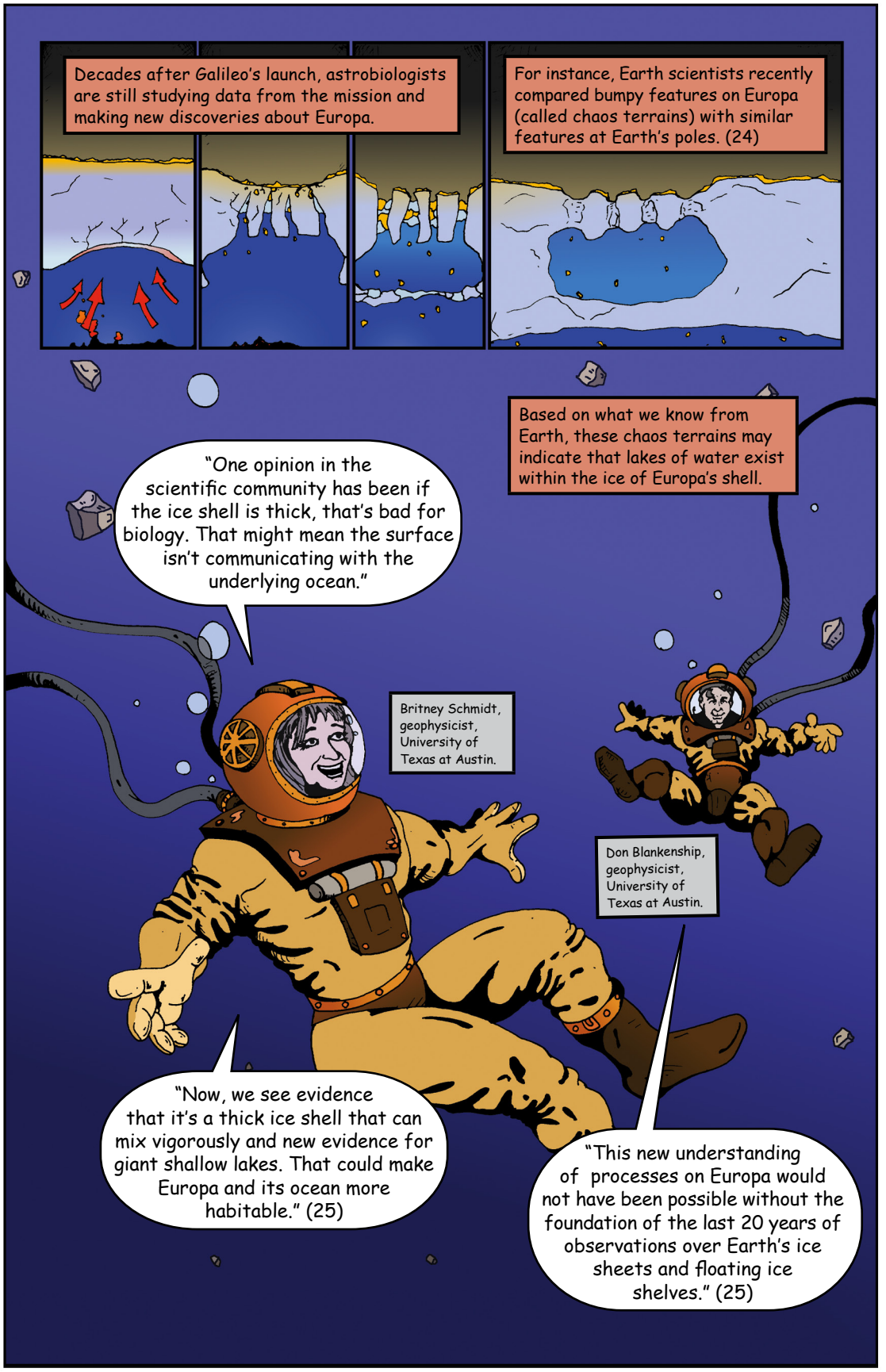

While photos of Io showed exciting geology in action, images from Europa were more puzzling. Europa was relatively smooth, but it had intersecting lines stretching all over its surface. (15)
In low resolution images from Voyager 1, scientists thought the lines could be evidence of tectonic processes.
However, high-resolution photos from Voyager 2 left scientists scratching their heads. The grooves of Europa's lines were not as deep, and the ridges not as high, as they had expected.
Europa was a mystery that called for more than just a passing visit... and that would come with Jupiter's first orbital mission—the Galileo spacecraft.

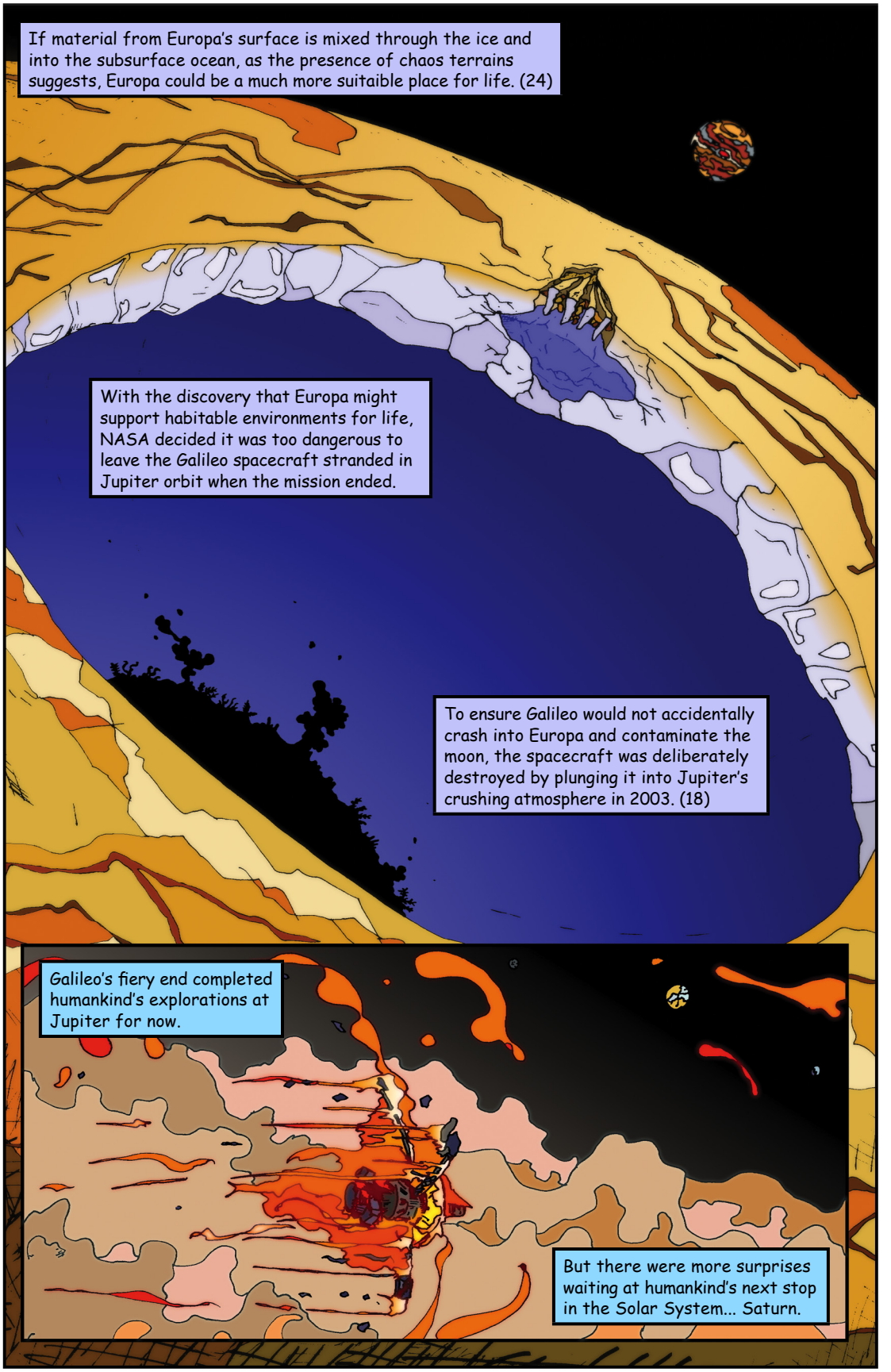

Political pressures almost stopped Galileo before it began. (8)
NASA had also approved the powerful Hubble Space Telescope...
...and taking on these two major programs was a huge strain on the budget. In 1981, Galileo was close to being cancelled.
WE WANT SCIENCE!
JUPITER NOW!
Give Jupiter a chance
GO GALILEO!!!
JUPITER
But the planetary science community made its voice heard, and, in the end, both missions were approved!
"Rarely have I ever seen such a successful lobbying campaign... It was masterfully done." (8)
Dick Malow, former staff director of the House HUD-Independent Agencies Appropriations Subcommittee
Galileo left Earth in October 1989 aboard the newly minted Space Shuttle.*
Galileo started work early with two Earth flybys. It spotted a huge impact basin on the far side of the Moon and signs of ancient lunar volcanism.
The spacecraft performed flybys of Venus, Earth and the asteroids Gaspra and Ida (with its tiny moon Dactyl).*
Almost six years after launch, Galileo arrived at Juptier and released an atmospheric probe.
The probe cut through Jupiter's turbulent atmosphere...
...gathering data about the planet's composition and weather.
After 58 minutes, it was vaporized!
*see Issue #3

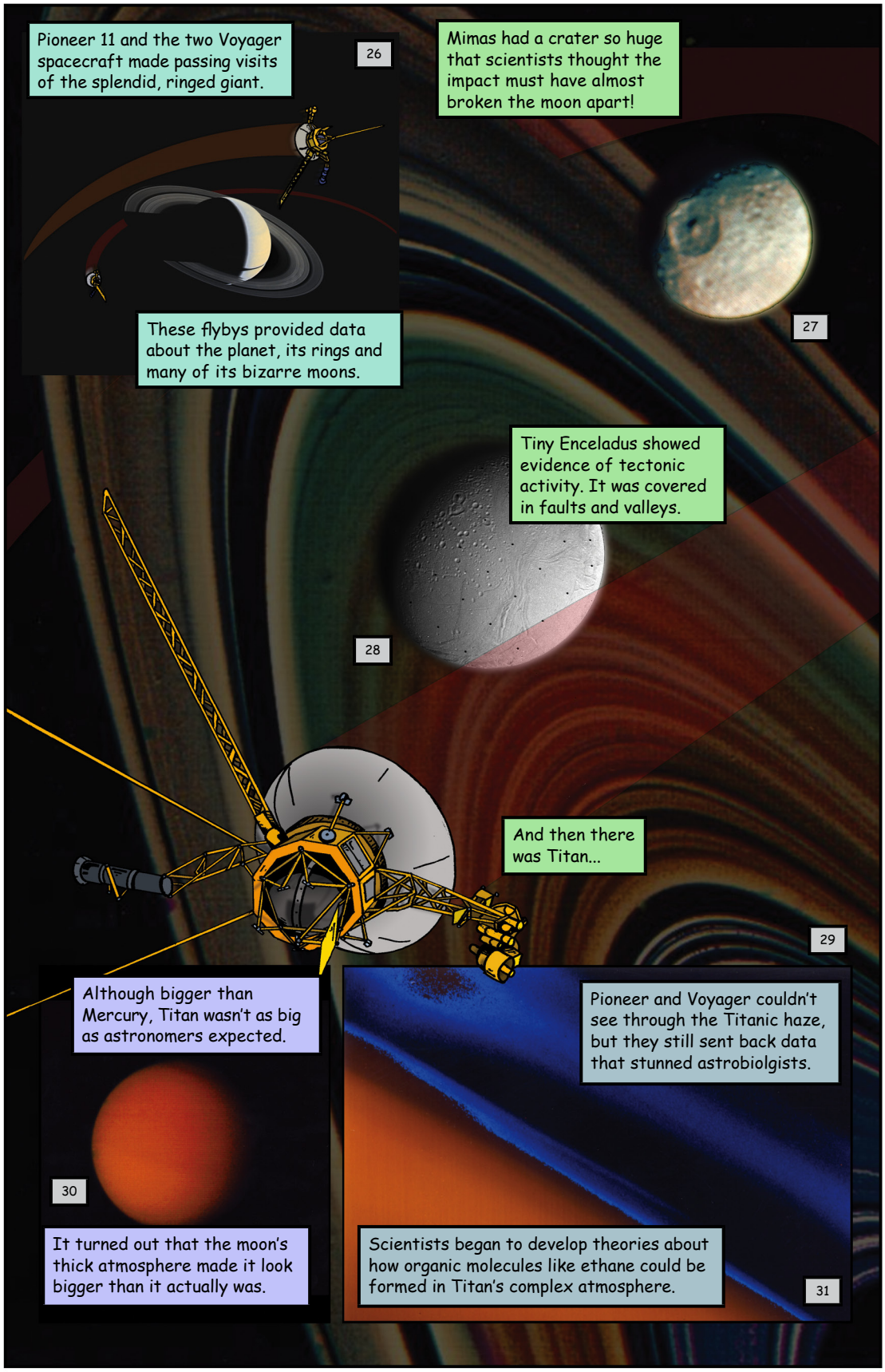

In July of 1994, Galileo witnessed something spectacular (and unexpected)...
The comet Shoemaker-Levy crashing into Jupiter!
"Galileo was positioned to see the actual impact on the backside and provide images and data concerning exactly the magnitude of those impacts." (16)
17
Galileo circled through the Jovian system and collected much more data than the Pioneers or Voyagers did on their passing visits.
Jim Erickson, former Galileo project manager.
For instance, Galileo measured Io's temperature and found volcanoes hotter than those on Earth!
But Galileo's real prize for astrobiologists was Europa. Images from the Voyagers were nothing compared to the spectacular world Galileo revealed.
Europa had few craters on its surface. This means that the ice is constantly changing, wiping away the evidence of impacts after they happen.
Although frozen solid, the surface of Europa had large 'ice rafts' the size of cities that appeared to have broken off and floated apart. Galileo also showed that Europa had a thin oxygen atmosphere and ionosphere. (18)
Astrobiologists traced the web of intersecting lines and fissures that covered Europa. They noted the nuances in their colors and the ways in which they reflected light.
Were the cracks fresh ice that was pushed to the surface from below?


Careful examination of the patterns and shapes led scientists to theorize that the icy surface was just a shell resting above a liquid layer deeper down. (19)
Then, Galileo's magnetometer spotted strange directional changes in Europa's magnetic field...
"The direction that a magnetic compass on Europa would point to flips around in a way that's best explained by the presence of a layer of electrically conducting liquid, such as saltwater, beneath the ice."
"We have good reason to believe the surface layers of Europa are made up of water that is either frozen or liquid."
"But ice is not a good conductor, and therefore we infer that the conductor may be a liquid ocean." (20)
"It will be interesting to see whether this same type of phenomenon occurs at Jupiter's moon Ganymede." (21)
Margaret Kivelson, principal investigator for Galileo's magnetometer.
Galileo did discover a magnetic field at Ganymede.
...raising questions about what lay beneath the large moon's solid surface. (22)
Similarly, Galileo found a magnetic field at Callisto...
But any ocean on Callisto would have to be extremely deep, because there are large craters all over Callisto's surface.


While the Voyagers were busy putting Europa on the astrobiological map, scientists made a fantastic discovery back on Earth.
Researchers Tjeerd van Andel and Jack Corliss spent six hours exploring the seafloor at 9,000 feet below the Pacific near the Galapagos Islands. (23)
They returned to the surface with samples that stank like rotten eggs.
The smell of hydrogen sulfide led scientists to discover that the depths of Earth's oceans support more life than anyone expected—and some organisms thrived **without** light from the Sun.
We learned of new energy sources, like undersea volcanoes, that supported entire communities of life.*
These findings raised many questions that changed our view of habitability and the origin and evolution of life.
Scientists began to explore environments on Earth that could be similar to a Europan ocean—from arctic islands to subsurface Antarctic lakes.
Engineers began developing instruments that could send future missions through the ice of Europa to explore its hidden depths.
*More on this in later issues


Decades after Galileo's launch, astrobiologists are still studying data from the mission and making new discoveries about Europa.
For instance, Earth scientists recently compared bumpy features on Europa (called chaos terrains) with similar features at Earth's poles. (24)
Based on what we know from Earth, these chaos terrains may indicate that lakes of water exist within the ice of Europa's shell.
"One opinion in the scientific community has been if the ice shell is thick, that's bad for biology. That might mean the surface isn't communicating with the underlying ocean."
Britney Schmidt, geophysicist, University of Texas at Austin.
Don Blankenship, geophysicist, University of Texas at Austin.
"Now, we see evidence that it's a thick ice shell that can mix vigorously and new evidence for giant shallow lakes. That could make Europa and its ocean more habitable." (25)
"This new understanding of processes on Europa would not have been possible without the foundation of the last 20 years of observations over Earth's ice sheets and floating ice shelves." (25)


If material from Europa's surface is mixed through the ice and into the subsurface ocean, as the presence of chaos terrains suggests, Europa could be a much more suitaible place for life. (24)
With the discovery that Europa might support habitable environments for life, NASA decided it was too dangerous to leave the Galileo spacecraft stranded in Jupiter orbit when the mission ended.
To ensure Galileo would not accidentally crash into Europa and contaminate the moon, the spacecraft was deliberately destroyed by plunging it into Jupiter's crushing atmosphere in 2003. (18)
Galileo's fiery end completed humankind's explorations at Jupiter for now.
But there were more surprises waiting at humankind's next stop in the Solar System... Saturn.


Pioneer 11 and the two Voyager spacecraft made passing visits of the splendid, ringed giant.
26
These flybys provided data about the planet, its rings and many of its bizarre moons.
Mimas had a crater so huge that scientists thought the impact must have almost broken the moon apart!
27
Tiny Enceladus showed evidence of tectonic activity. It was covered in faults and valleys.
28
And then there was Titan...
29
Pioneer and Voyager couldn't see through the Titanic haze, but they still sent back data that stunned astrobiolgists.
Although bigger than Mercury, Titan wasn't as big as astronomers expected.
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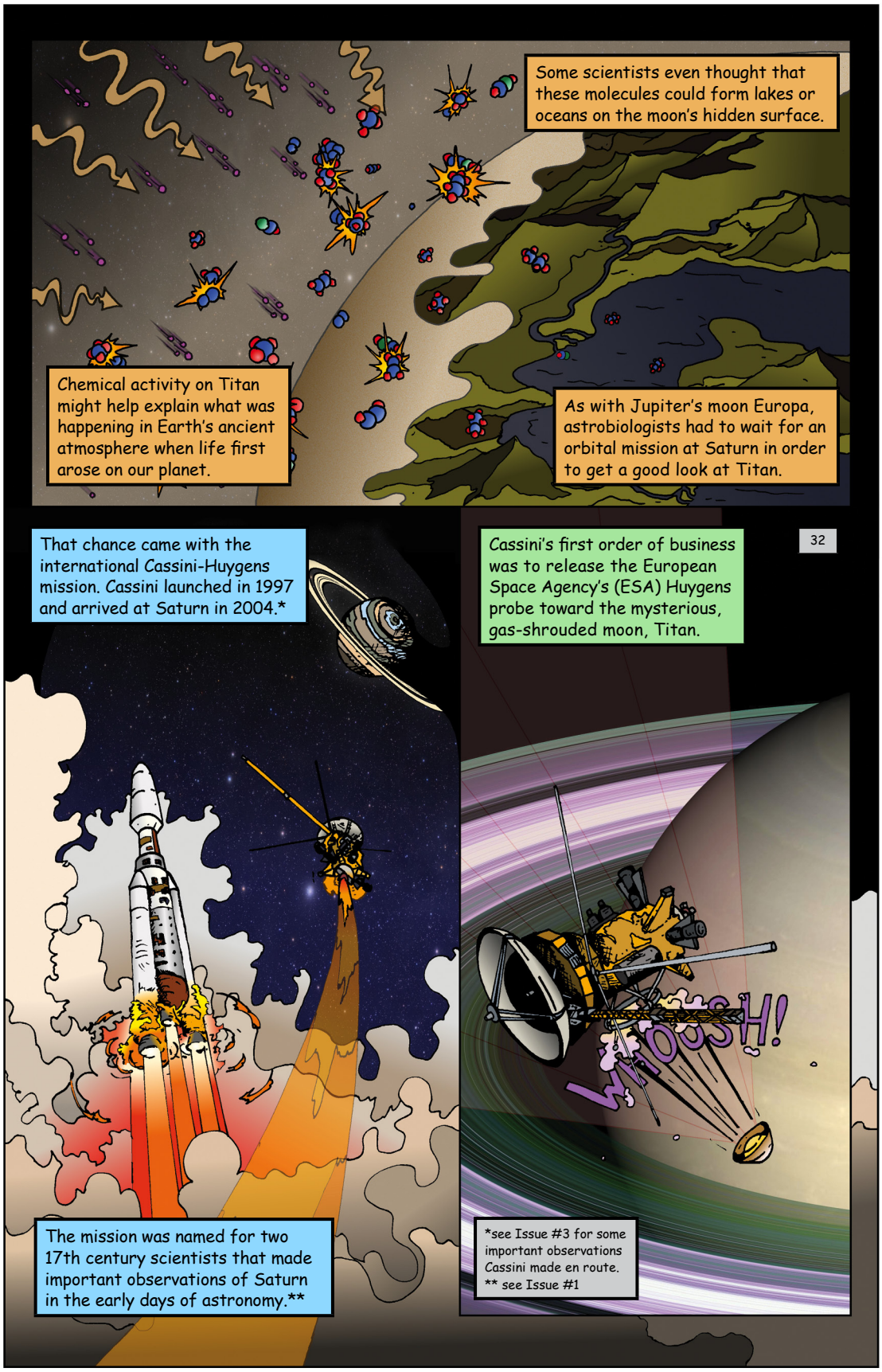
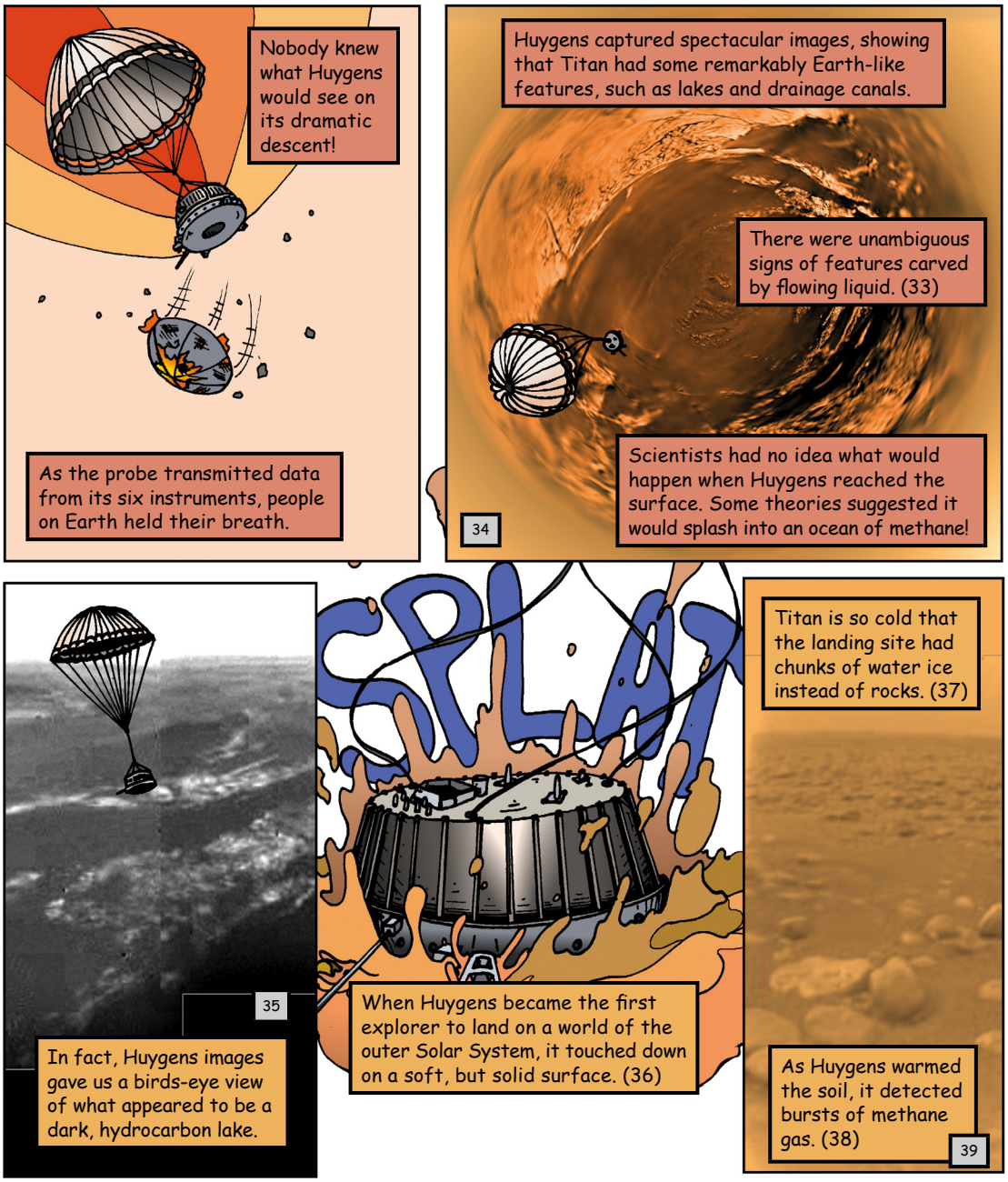
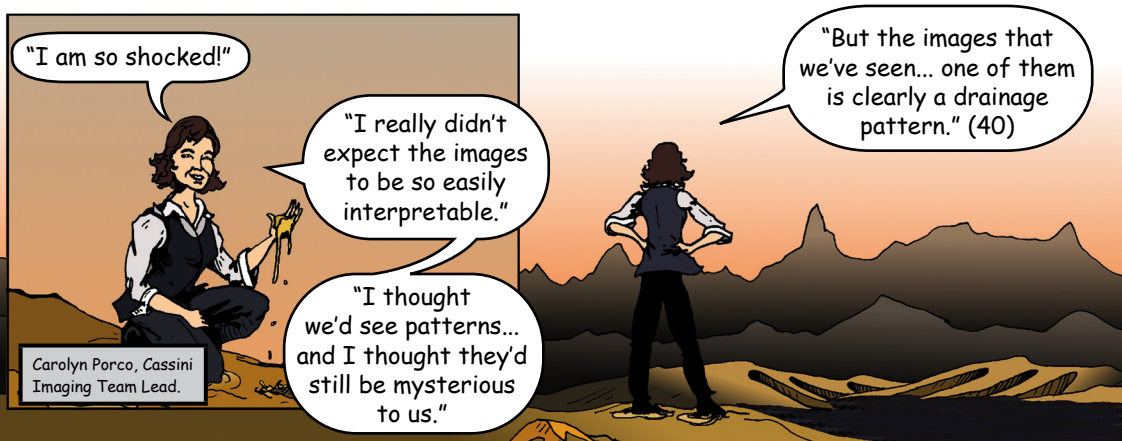
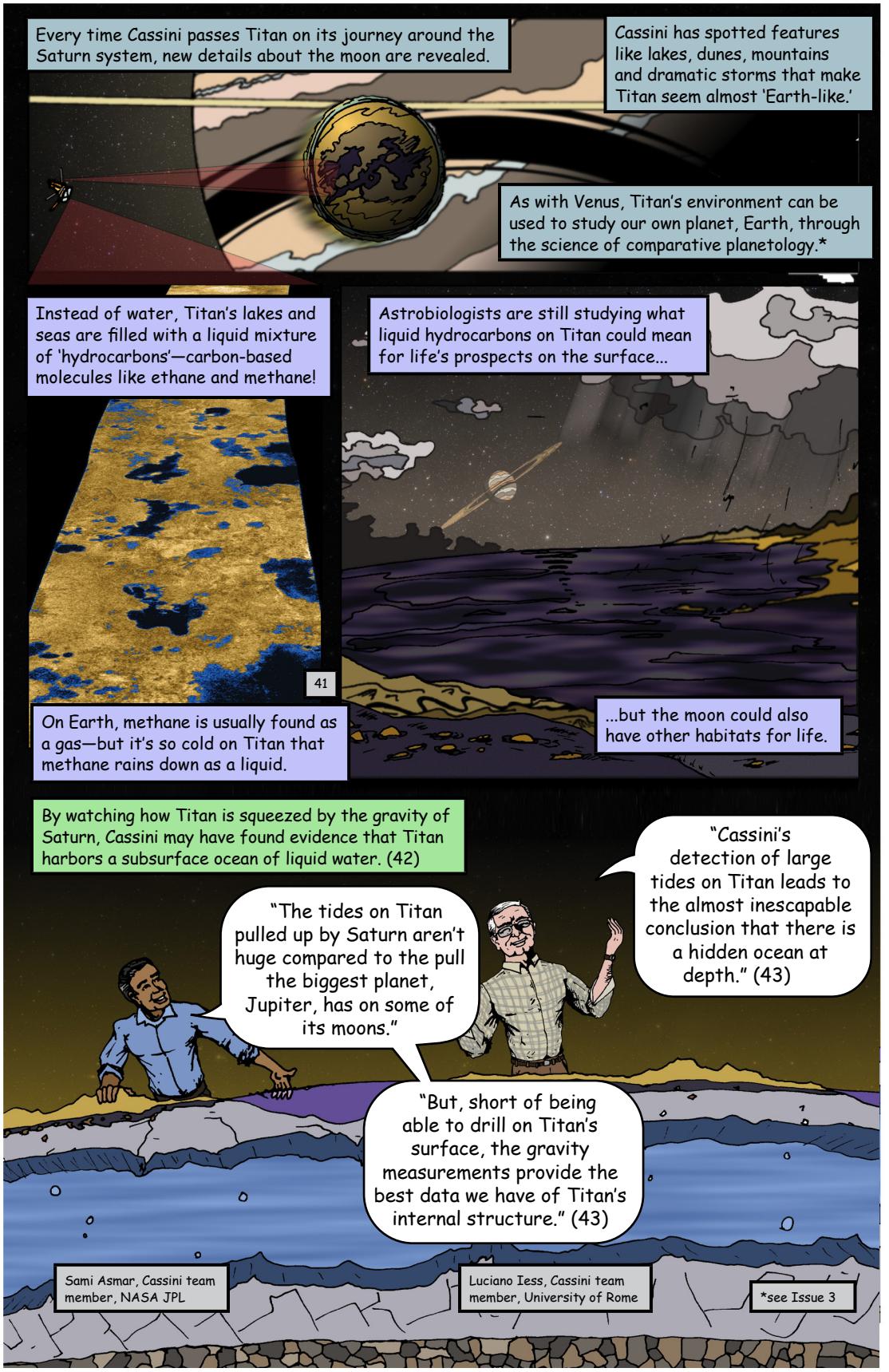
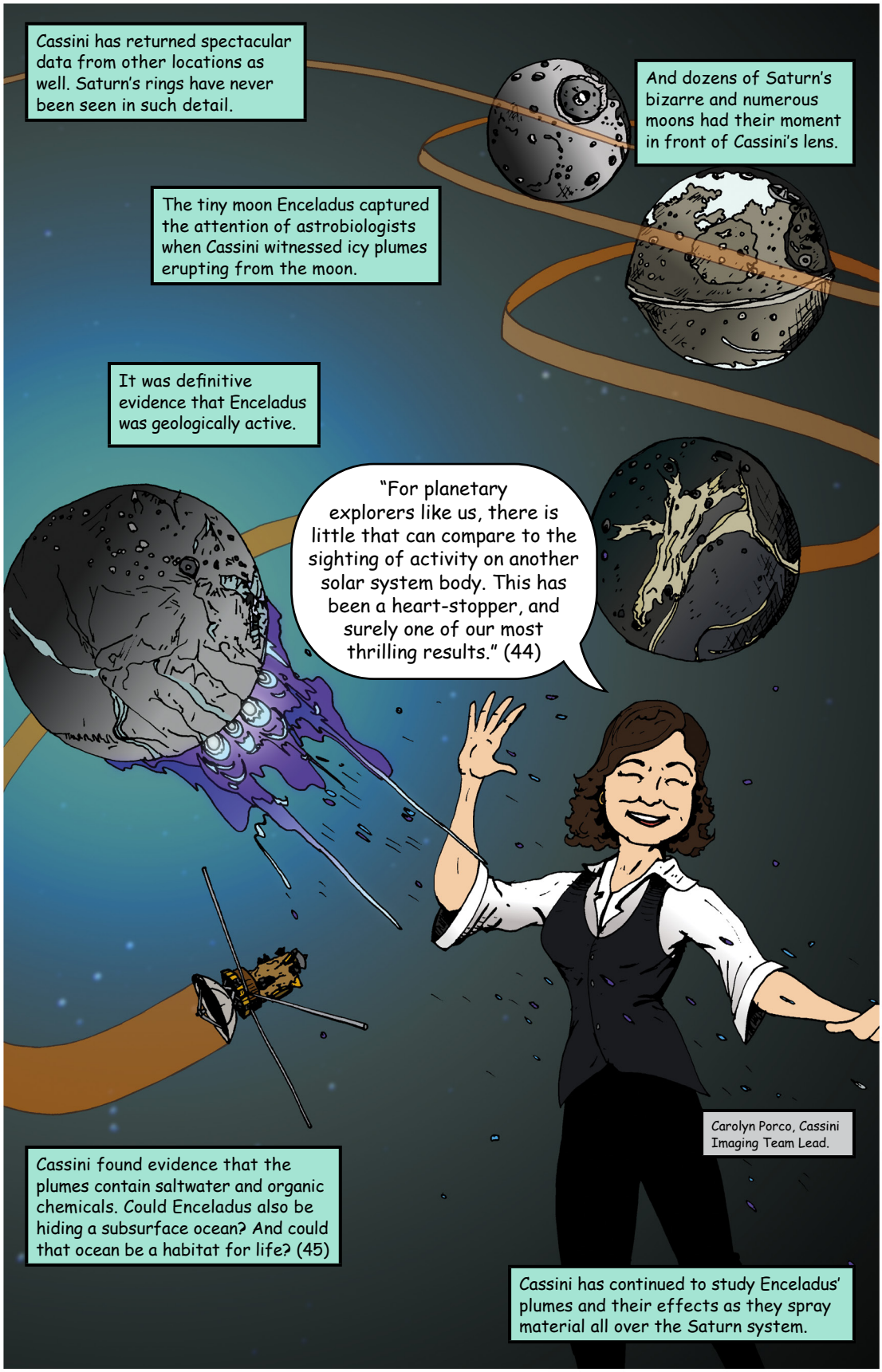
It turned out that the moon's thick atmosphere made it look bigger than it actually was.
Scientists began to develop theories about how organic molecules like ethane could be formed in Titan's complex atmosphere.
31

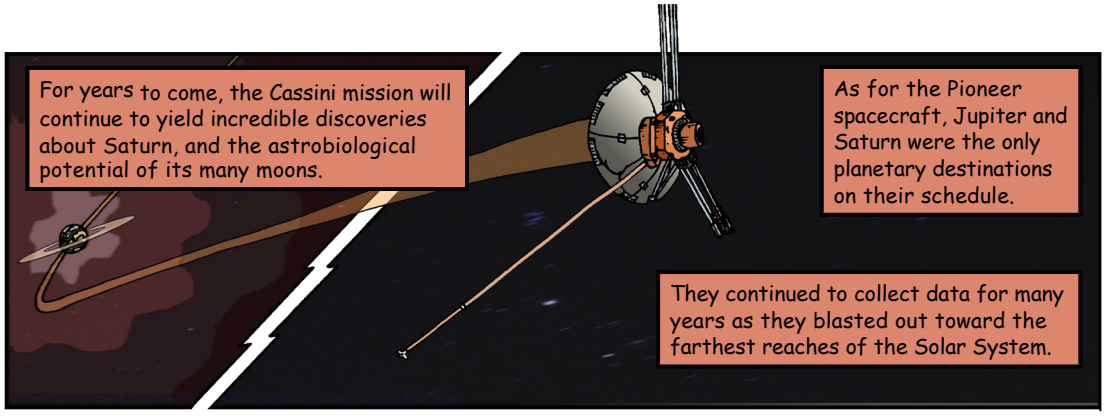

Some scientists even thought that these molecules could form lakes or oceans on the moon's hidden surface.
Chemical activity on Titan might help explain what was happening in Earth's ancient atmosphere when life first arose on our planet.
As with Jupiter's moon Europa, astrobiologists had to wait for an orbital mission at Saturn in order to get a good look at Titan.
That chance came with the international Cassini-Huygens mission. Cassini launched in 1997 and arrived at Saturn in 2004.*
Cassini's first order of business was to release the European Space Agency's (ESA) Huygens probe toward the mysterious, gas-shrouded moon, Titan.
32
WHOOSH!
The mission was named for two 17th century scientists that made important observations of Saturn in the early days of astronomy.**
*see Issue #3 for some important observations Cassini made en route.
** see Issue #1


Nobody knew what Huygens would see on its dramatic descent!
As the probe transmitted data from its six instruments, people on Earth held their breath.
Huygens captured spectacular images, showing that Titan had some remarkably Earth-like features, such as lakes and drainage canals.
There were unambiguous signs of features carved by flowing liquid. (33)
Scientists had no idea what would happen when Huygens reached the surface. Some theories suggested it would splash into an ocean of methane!
34
35
In fact, Huygens images gave us a birds-eye view of what appeared to be a dark, hydrocarbon lake.
SPLAT
When Huygens became the first explorer to land on a world of the outer Solar System, it touched down on a soft, but solid surface. (36)
Titan is so cold that the landing site had chunks of water ice instead of rocks. (37)
As Huygens warmed the soil, it detected bursts of methane gas. (38)
39


"I am so shocked!"
"I really didn't expect the images to be so easily interpretable."
"I thought we'd see patterns... and I thought they'd still be mysterious to us."
Carolyn Porco, Cassini Imaging Team Lead.
"But the images that we've seen... one of them is clearly a drainage pattern." (40)

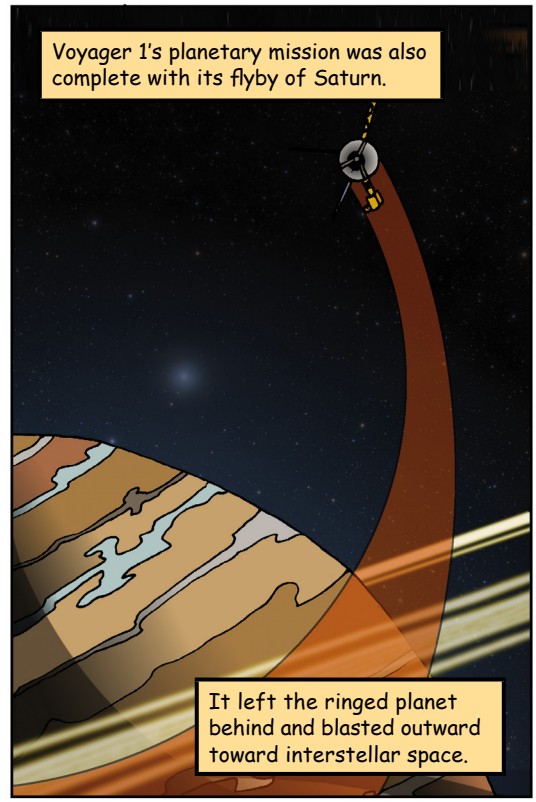

Every time Cassini passes Titan on its journey around the Saturn system, new details about the moon are revealed.
Cassini has spotted features like lakes, dunes, mountains and dramatic storms that make Titan seem almost 'Earth-like.'
As with Venus, Titan's environment can be used to study our own planet, Earth, through the science of comparative planetology.*
Instead of water, Titan's lakes and seas are filled with a liquid mixture of 'hydrocarbons'—carbon-based molecules like ethane and methane!
41
On Earth, methane is usually found as a gas—but it's so cold on Titan that methane rains down as a liquid.
Astrobiologists are still studying what liquid hydrocarbons on Titan could mean for life's prospects on the surface...
...but the moon could also have other habitats for life.
By watching how Titan is squeezed by the gravity of Saturn, Cassini may have found evidence that Titan harbors a subsurface ocean of liquid water. (42)
"Cassini's detection of large tides on Titan leads to the almost inescapable conclusion that there is a hidden ocean at depth." (43)
"The tides on Titan pulled up by Saturn aren't huge compared to the pull the biggest planet, Jupiter, has on some of its moons."
"But, short of being able to drill on Titan's surface, the gravity measurements provide the best data we have of Titan's internal structure." (43)
Sami Asmar, Cassini team member, NASA JPL
Luciano Iess, Cassini team member, University of Rome
*see Issue 3


Cassini has returned spectacular data from other locations as well. Saturn's rings have never been seen in such detail.
And dozens of Saturn's bizarre and numerous moons had their moment in front of Cassini's lens.
The tiny moon Enceladus captured the attention of astrobiologists when Cassini witnessed icy plumes erupting from the moon.
It was definitive evidence that Enceladus was geologically active.
"For planetary explorers like us, there is little that can compare to the sighting of activity on another solar system body. This has been a heart-stopper, and surely one of our most thrilling results." (44)
Carolyn Porco, Cassini Imaging Team Lead.
Cassini found evidence that the plumes contain saltwater and organic chemicals. Could Enceladus also be hiding a subsurface ocean? And could that ocean be a habitat for life? (45)
Cassini has continued to study Enceladus' plumes and their effects as they spray material all over the Saturn system.


For years to come, the Cassini mission will continue to yield incredible discoveries about Saturn, and the astrobiological potential of its many moons.
As for the Pioneer spacecraft, Jupiter and Saturn were the only planetary destinations on their schedule.
They continued to collect data for many years as they blasted out toward the farthest reaches of the Solar System.


On January 23, 2003, a final, weak signal was recieved from Pioneer 10. The silent craft is now flying into interstellar space toward the red star Aldebaran. (46)
Like its sister spacecraft, Pioneer 11 is now at the distant edge of the Solar System, but it is silently headed toward the star Sagittarius.
47


"Originally designed for a 21- month mission, Pioneer 10 lasted more than 30 years... I guess you could say we got our money's worth." (7)
"We can say that we sent Pioneer 10 off to tweak a dragon's tail, and it did that and more. It gave it a really good yank and... it survived." (2)
Robert Kraemer, NASA HQ
Larry Lasher, Pioneer Project Manager


Voyager 1's planetary mission was also complete with its flyby of Saturn.
It left the ringed planet behind and blasted outward toward interstellar space.

Voyager 2, however, had more work to do.

While Voyager 1 rocketed away, Voyager 2 continued to Uranus and Neptune and completed the origininal 'Grand Tour' of the planets proposed in the 1960s (see page 3).

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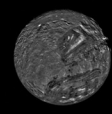

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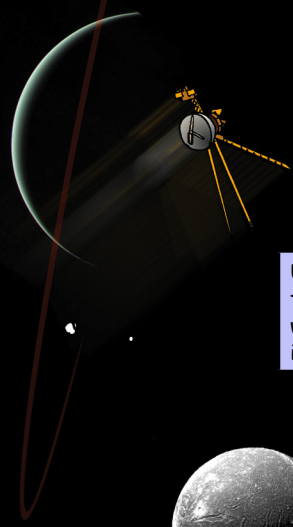
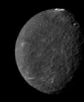
Uranus and Neptune can be seen by telescopes on Earth, but scientists didn't know what to expect when Voyager 2 arrived.



Uranus itself appeared to be fairly inactive, with little variation in its layers of clouds.



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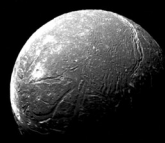
But Voyager 2 discovered 10 new moons and 2 new rings around the planet. (14)



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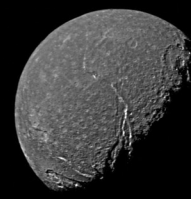

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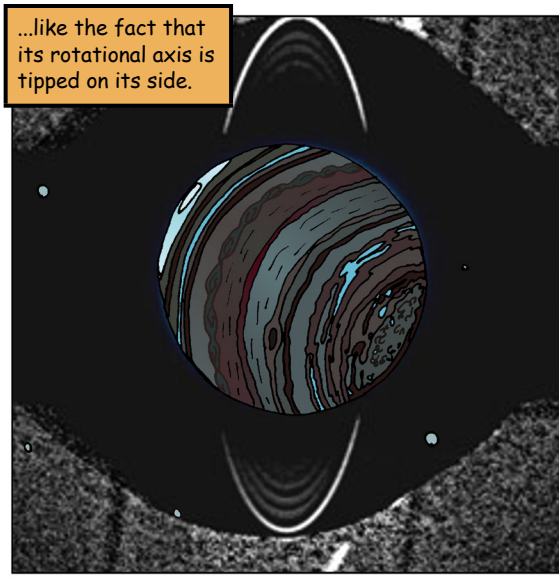
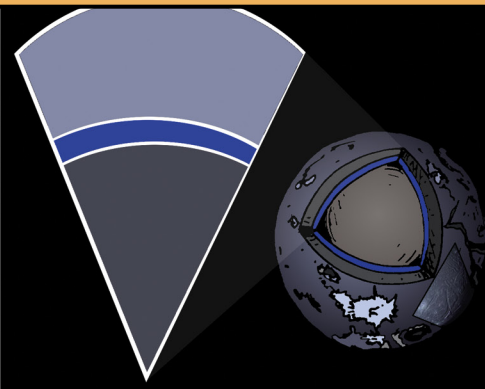
Uranus' five largest moons showed complex surfaces that indicated past geological activity.

Uranus may have looked boring at first, but it actually has some pretty strange features...

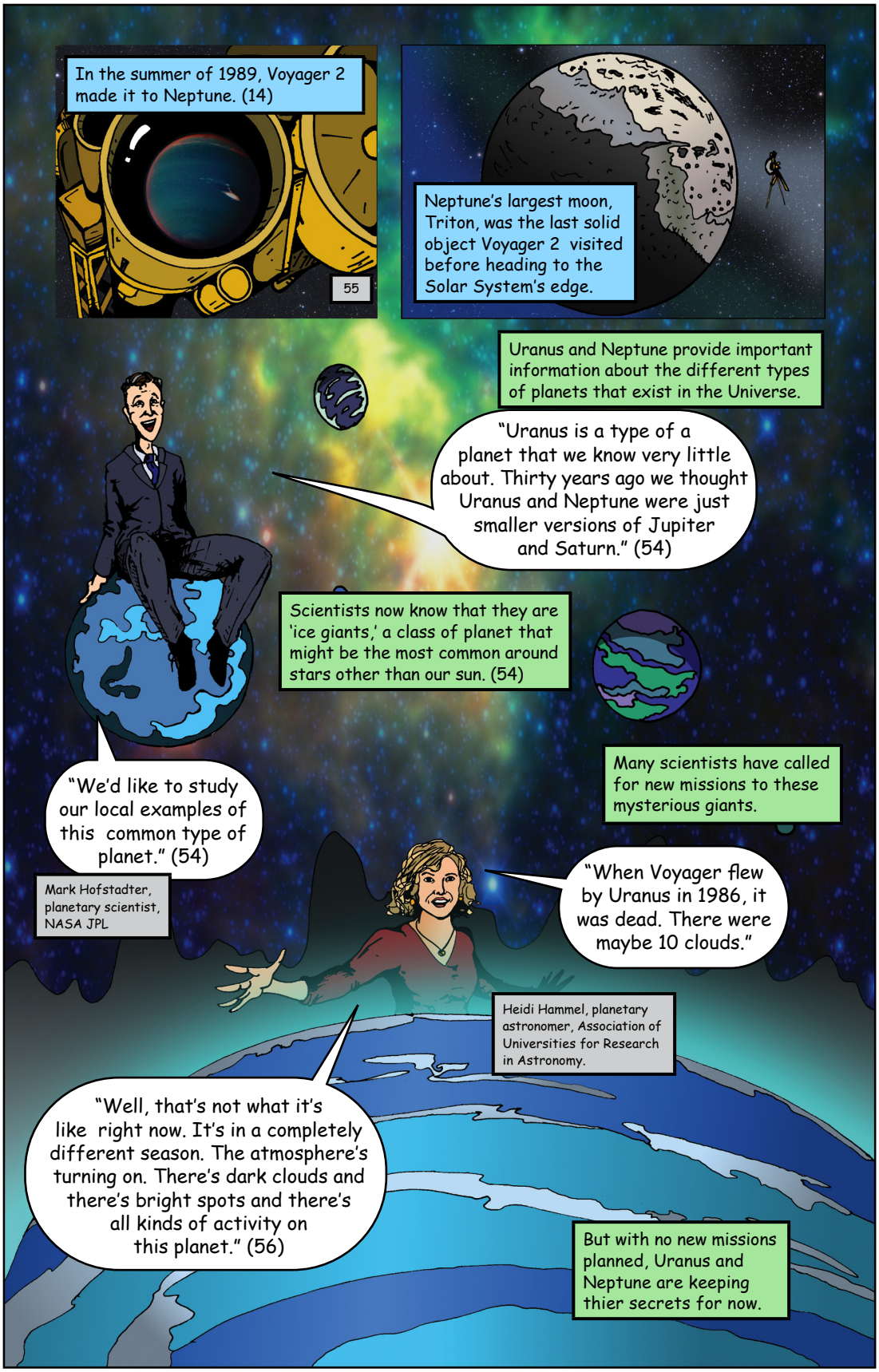
...like the fact that its rotational axis is tipped on its side.



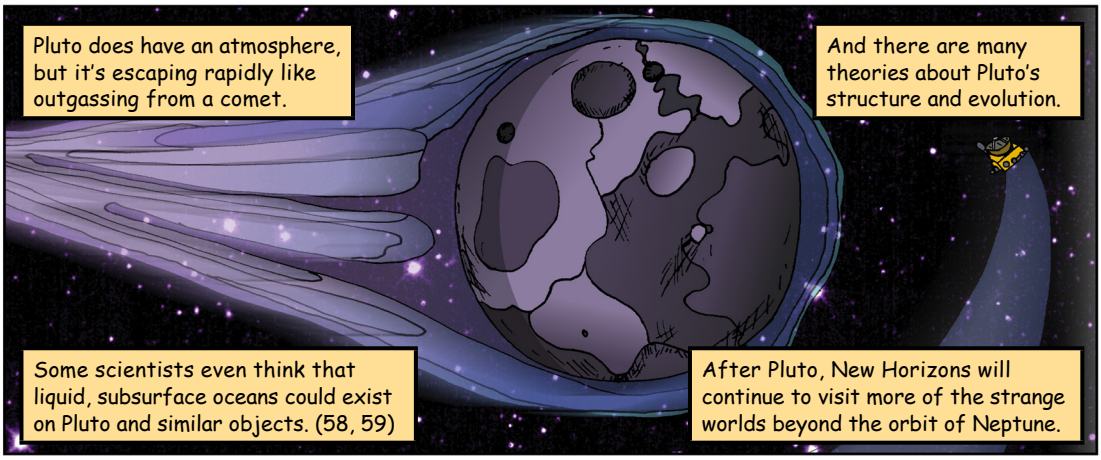
Telescopes on Earth have revealed clouds and huge wind storms, proving that Uranus is more dynamic than it first looked in Voyager images. (53)

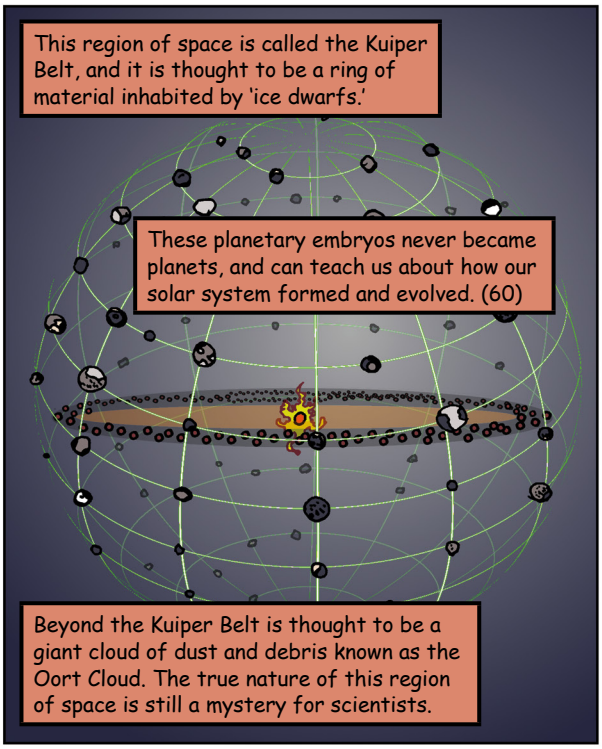


Some studies even suggest that moons of Uranus, like Titania, might have subsurface oceans. (54)

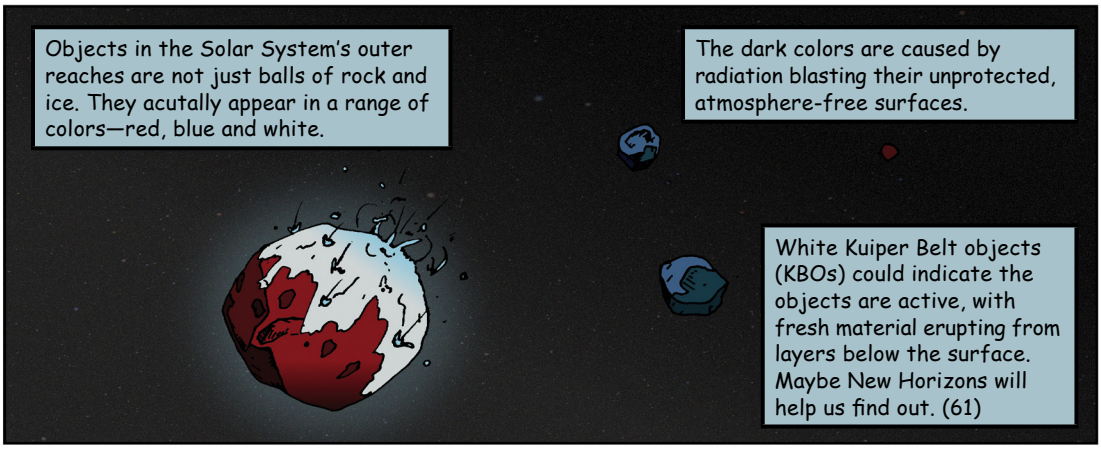

In the summer of 1989, Voyager 2 made it to Neptune. (14)
55
Neptune's largest moon, Triton, was the last solid object Voyager 2 visited before heading to the Solar System's edge.
Uranus and Neptune provide important information about the different types of planets that exist in the Universe.
"Uranus is a type of a planet that we know very little about. Thirty years ago we thought Uranus and Neptune were just smaller versions of Jupiter and Saturn." (54)
Scientists now know that they are 'ice giants,' a class of planet that might be the most common around stars other than our sun. (54)
Many scientists have called for new missions to these mysterious giants.
"We'd like to study our local examples of this common type of planet." (54)
Mark Hofstadter, planetary scientist, NASA JPL
"When Voyager flew by Uranus in 1986, it was dead. There were maybe 10 clouds."
Heidi Hammel, planetary astronomer, Association of Universities for Research in Astronomy.
"Well, that's not what it's like right now. It's in a completely different season. The atmosphere's turning on. There's dark clouds and there's bright spots and there's all kinds of activity on this planet." (56)
But with no new missions planned, Uranus and Neptune are keeping thier secrets for now.

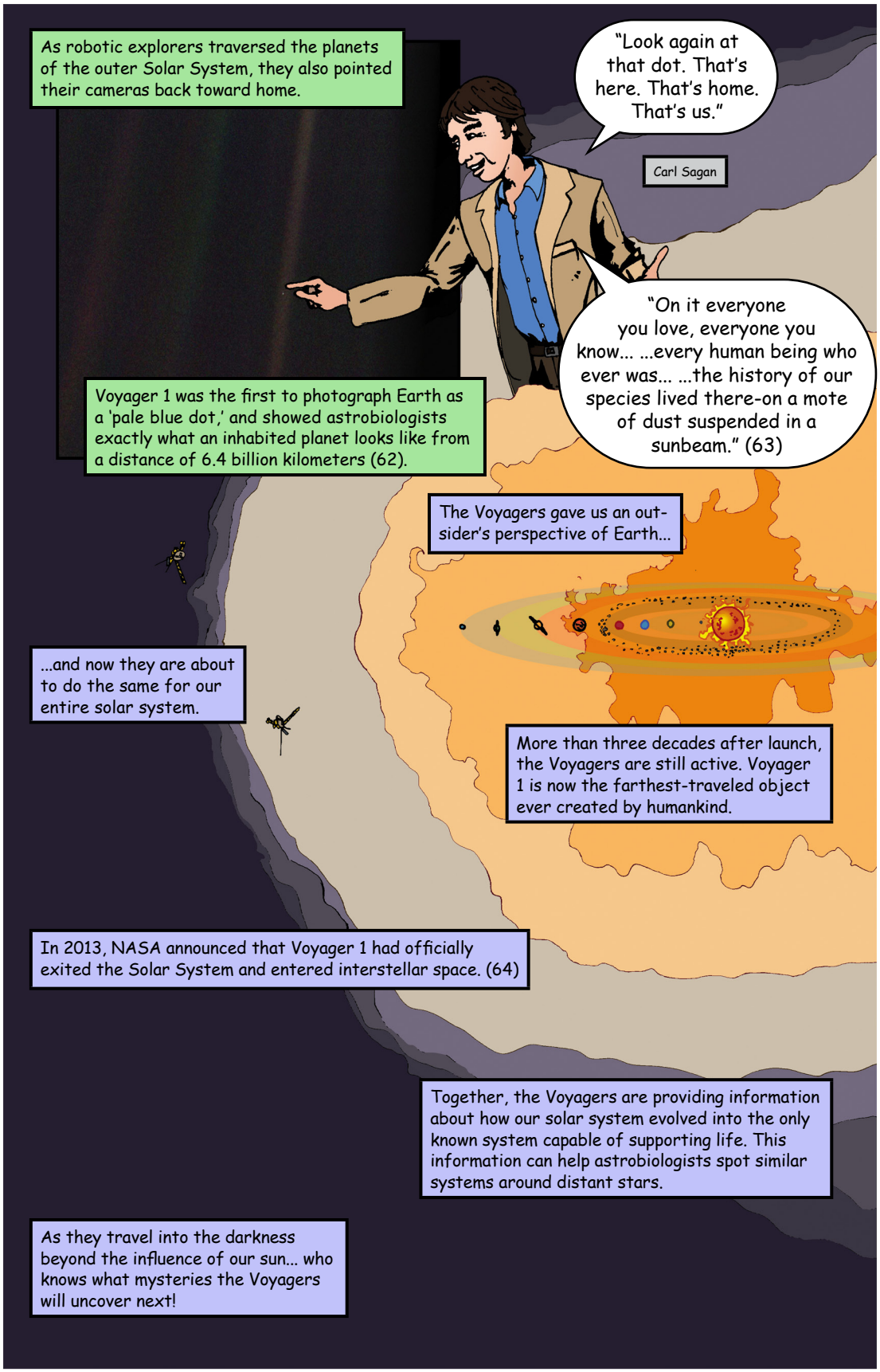

With Voyager 2, all of the major planets in the Solar System have been visited.
Jupiter and Saturn have been orbited, and in 2016 Jupiter will have a new visitor -the Juno mission.
Juno will provide new insights into how planetary systems, and especially gas planets, form.
In the decades to come, other missions could provide details about habitability in the Jovian system—such as ESA's Jupiter Icy Moons Explorer (JUICE), currently in development.
Beyond the major planets, many hidden corners of the outer Solar System still remain unexplored.
NASA's New Horizons mission is en route to one such place.
New Horizons was launched in 2006 and is now well on its way to small, distant Pluto, which is known as a 'dwarf planet.'
Very little is known about objects beyond the orbit of Neptune, such as Pluto and its largest moon Charon.
Even the highest-resolution images from ground-based and orbital telescopes see these tiny, distant objects as little more than points of light.
NASA

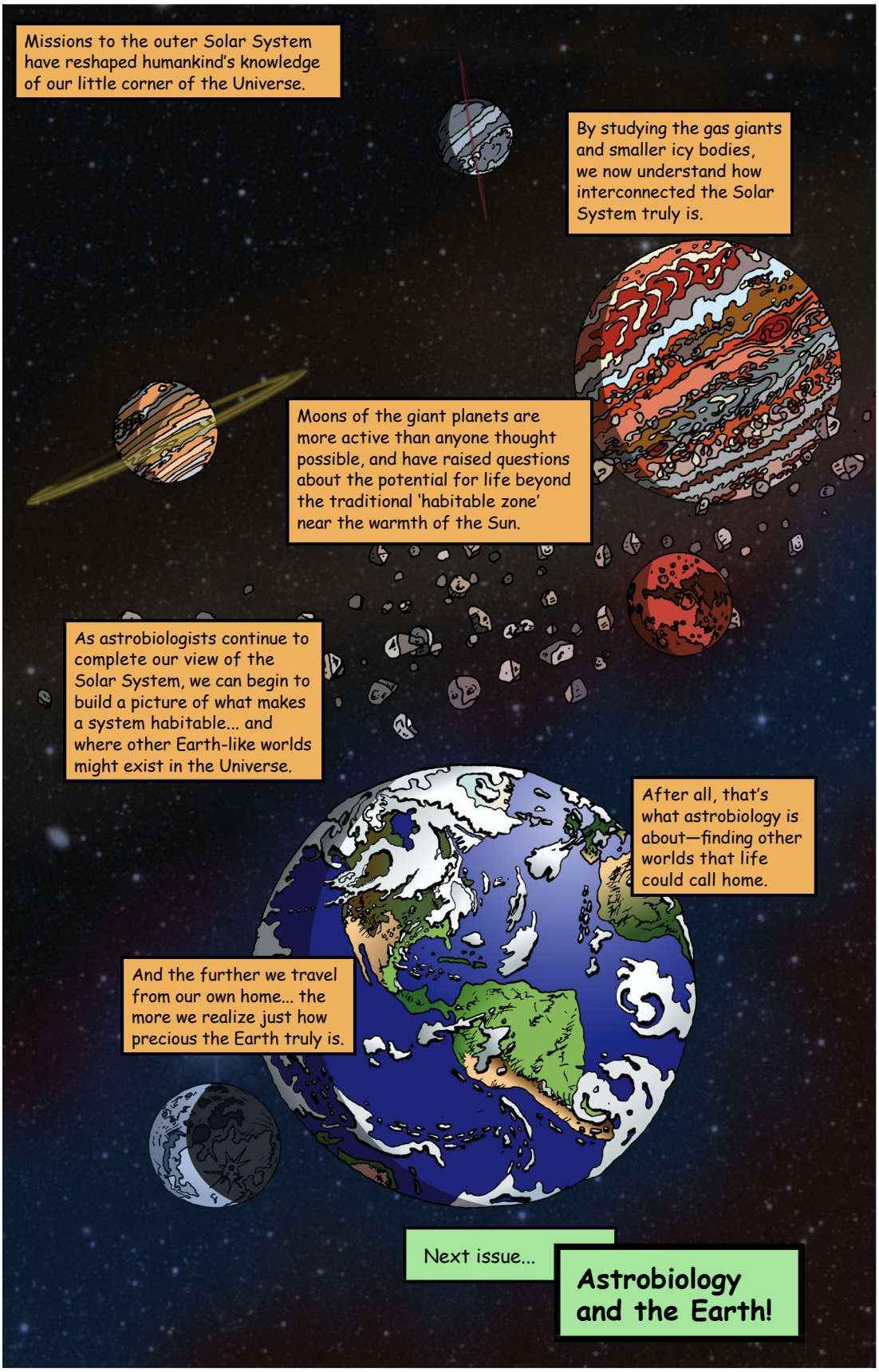

Pluto does have an atmosphere, but it's escaping rapidly like outgassing from a comet.
And there are many theories about Pluto's structure and evolution.
Some scientists even think that liquid, subsurface oceans could exist on Pluto and similar objects. (58, 59)
After Pluto, New Horizons will continue to visit more of the strange worlds beyond the orbit of Neptune.


This region of space is called the Kuiper Belt, and it is thought to be a ring of material inhabited by 'ice dwarfs.'
These planetary embryos never became planets, and can teach us about how our solar system formed and evolved. (60)
Beyond the Kuiper Belt is thought to be a giant cloud of dust and debris known as the Oort Cloud. The true nature of this region of space is still a mystery for scientists.


But these distant regions of the Solar System are important to monitor because they may be a source of comets and other objects...
...which occassionally come crashing into the inner Solar System and impact worlds like Earth.


Objects in the Solar System's outer reaches are not just balls of rock and ice. They acutally appear in a range of colors—red, blue and white.
The dark colors are caused by radiation blasting their unprotected, atmosphere-free surfaces.
White Kuiper Belt objects (KBOs) could indicate the objects are active, with fresh material erupting from layers below the surface. Maybe New Horizons will help us find out. (61)


As robotic explorers traversed the planets of the outer Solar System, they also pointed their cameras back toward home.
"Look again at that dot. That's here. That's home. That's us."
Carl Sagan
"On it everyone you love, everyone you know... ...every human being who ever was... ...the history of our species lived there-on a mote of dust suspended in a sunbeam." (63)
Voyager 1 was the first to photograph Earth as a 'pale blue dot,' and showed astrobiologists exactly what an inhabited planet looks like from a distance of 6.4 billion kilometers (62).
The Voyagers gave us an outsider's perspective of Earth...
...and now they are about to do the same for our entire solar system.
More than three decades after launch, the Voyagers are still active. Voyager 1 is now the farthest-traveled object ever created by humankind.
In 2013, NASA announced that Voyager 1 had officially exited the Solar System and entered interstellar space. (64)
Together, the Voyagers are providing information about how our solar system evolved into the only known system capable of supporting life. This information can help astrobiologists spot similar systems around distant stars.
As they travel into the darkness beyond the influence of our sun... who knows what mysteries the Voyagers will uncover next!


Missions to the outer Solar System have reshaped humankind's knowledge of our little corner of the Universe.
By studying the gas giants and smaller icy bodies, we now understand how interconnected the Solar System truly is.
Moons of the giant planets are more active than anyone thought possible, and have raised questions about the potential for life beyond the traditional 'habitable zone' near the warmth of the Sun.
As astrobiologists continue to complete our view of the Solar System, we can begin to build a picture of what makes a system habitable... and where other Earth-like worlds might exist in the Universe.
After all, that's what astrobiology is about—finding other worlds that life could call home.
And the further we travel from our own home... the more we realize just how precious the Earth truly is.
Next issue...
Astrobiology and the Earth!

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