Produced by the NASA Astrobiology Program to commemorate 50 years 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.
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 second in what we intend to be a series of graphic history books. Though not comprehensive, the series has been conceived to highlight key moments and key people in the field as it explains how Astrobiology came to be.

-Linda Billings, Editor
Astrobiology, the study of life's origin, evolution, and distribution in the Universe, has been a key part of NASA's research since the agency began. When NASA first launched missions into Earth orbit and beyond, Astrobiology was ready for the ride!

**Issue 2—Missions to Mars.**

NASA has explored many places in the Solar System, but one destination has been particularly important to Exobiology and Astrobiology—Mars.

When the space age began, Mars was a complete mystery. Now we know the planet may have been more Earth-like in its past. Astrobiologists wonder, what was ancient Mars like? Long ago, could Mars have supported life as we know it?

The history of missions to Mars is full of struggle and triumph. Mars is a dangerous and difficult planet to visit. The extreme environment of the planet includes frigid temperatures, damaging dust storms, low gravity, and a thin atmosphere. Many missions to Mars have ended in failure, but the missions that were successful have provided fascinating evidence of Mars' potential habitability.

The year 2010 marked half a century of Exobiology and Astrobiology research at NASA. In 2011, a new era of Astrobiology research in Mars exploration began with the launch of NASA's Mars Science Laboratory. Today, NASA and other agencies around the world are building new missions to explore the red planet.

But first... let's take a closer look at Mars' role in the early history of Exobiology and Astrobiology.
NASA’s new Exobiology program, established in 1960 (see Issue 1), attracted a host of talented scientists.

“Why don’t you stay and set up a lab for the study of the origin of life?” (2)

“And that’s what we did immediately” (2)

NASA forged ahead with the lunar program and built facilities for analyzing space material such as lunar samples and meteorites...

...but exobiologists also had their sights set on our closest planetary neighbors—Venus and Mars.

“More may be added to man’s knowledge of the planet Venus than has been gained in all the thousands of years of recorded history.”* (10)

Mariner 5 (1967) turned back to Venus. Observations of its harsh environment by Mariners 2 and 5 helped solidify the idea that Mars was a better place to hunt for life.

Our vision of Mars began to evolve with Mariners 6 and 7 (1969). These two spacecraft mapped 20% of the martian surface and provided detailed images of many of the planet’s unique features.

Mariner 9 (1971) was the first spacecraft to enter orbit around another planet. The mission truly unveiled Mars, mapping 80% of the surface. Mariner 9 returned the first images of landmarks such as Valles Marineris, the vast canyon named in the spacecraft’s honor.

The program’s final mission, Mariner 10 (1973), didn’t visit Mars, but it demonstrated techniques that would be used in many space missions to follow. Mariner 10 was the first spacecraft to visit multiple planets, and the first to use the gravitational assist of one planet (Venus) to build up enough speed to visit a second (Mercury).

The Soviet Union also set its sights on Mars with the Mars 2 (1971), Mars 3 (1971), and Mars 5 (1973) missions. Each suffered difficulties, but collected data about the planet’s surface and atmospheric conditions. (20)
As early as 1959, NASA was developing instruments for detecting life. Mars quickly topped the list of places where NASA could put this technology to use. The early focus on Mars led to a major milestone in the history of Exobiology and Astrobiology.

Viking 1 and Viking 2 each had a lander and an orbiter that were sent to Mars. Each lander carried 14 experiments, including a set of investigations specifically designed to search for evidence of martian life.

In 1961, NASA officials invited British scientist James Lovelock, an expert in life detection technology, to work with the U.S. space program. He had many ideas for life detection experiments and worked on early designs for a Mars probe in 1965.

Lovelock had interesting ideas about searching for life based on biological reactions that cells perform, rather than identifying physical structures such as DNA in cells.

“We must concentrate on concepts that are not ‘Earthcentric.’ We ought to look for entropy-reduction phenomena.” (8)

Lovelock viewed the planet Earth as a complete living system, and began to discuss these ideas with Carl Sagan, Dian Hitchcock and Normon Horowitz, then head of the Biology Division at NASA’s Jet Propulsion Laboratory (JPL). (4)

“I think I know some people you should meet... But Lovelock’s groundbreaking theories are a story for another time...
Lovelock’s work with NASA helped define Viking’s life detection experiments. These experiments were designed to cultivate microorganisms (should there be any) in martian soil samples by introducing water and measuring signs of growth.

“CO₂ was [the major] component [in Mars’ atmosphere], with only a trace of water vapor. That discovery gave me and my collaborators, George Hobby and Jerry Hubbard, the impetus to design an instrument that would search for life on a dry planet. That instrument was the pyrolytic release experiment.” (4)

Horowitz’s new understanding of Mars led him and his colleagues to search for life and test Viking’s equipment in similarly inhospitable environments on Earth, such as the Dry Valleys of Antarctica and Chile’s Atacama Desert.

Scientists such as Gil Levin and Wolf Vishniac began to test their Viking life detection experiments on soils from the Antarctic Dry Valleys. Vishniac detected microbial life in soils that Horowitz and his colleagues thought were sterile, making the questions about life’s potential on Mars even more complicated.

So before Viking even launched, the mission spurred research about life on Earth. Scientists worked hard to develop a basic definition of “life” so that they knew what to look for on Mars. (4)
In December 1969, NASA selected experiments. They included Horowitz’s pyrolytic release experiment, Levin’s labeled release experiment, Vishniac’s ‘Wolf Trap’ (later removed) and Oyama’s gas exchange experiment.

The life detection experiments were fitted into a single package for the landers, which also carried miniaturized GC/MSs* to separate and identify organic compounds by molecular weight.

Even if the biology experiments showed negative results, the GC/MS could find organic molecules that proved cells might be in the samples.

“The fact is that nothing we have learned about Mars, in contrast to Venus, excludes it as a possible abode of life...”

...It is certainly true that no terrestrial species could survive under average martian conditions as we know them, except in a dormant state, but if we admit the possibility that Mars once had a more favorable climate which was gradually transformed to the severe one we find there today...

...and if we accept the possibility that life arose on the planet during this earlier epoch, then we cannot exclude the possibility that martian life succeeded in adapting itself to the changing conditions and survives there still.” (21)

“[Identifying organic compounds] seemed important... because we hoped that the nature of Martian organic molecules would provide a sensitive indicator of the chemical and physical environment in which they formed.

Furthermore, we hoped that the details of their structures would indicate which of many possible biotic and abiotic syntheses are occurring on Mars.” (4)

“[Identifying organic compounds] seemed important...” because we hoped that the nature of Martian organic molecules would provide a sensitive indicator of the chemical and physical environment in which they formed.

“I consider [the GC/MS] the most important instrument on Viking.” (4)

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*Gas Chromatograph/ Mass Spectrometers
Cameras on the lander revealed a surface far different—and far more familiar—than that of the Moon. On July 28, the lander’s mechanical arm scooped samples into the instruments. To prevent contamination of Mars, the Viking Landers were assembled in a special clean room, baked in dry heat to kill any microorganisms, and kept in isolation until landing on Mars.

On July 20, 1976—seven years after the Apollo 11 lunar landing—the Viking 1 lander touched down on the flat, martian plain of Chryse Planitia.

On September 3rd, Viking 2 landed halfway around the planet on the plain of Utopia.

The world watched as results began to pour in from the Viking experiments.

All of the biology experiments showed evidence of activity in the samples after the very first test. The pyrolytic release experiment gave one reading consistent with photosynthesis occurring, but the initial result couldn’t be repeated. The gas release experiment showed oxygen released from the Mars soil—but many scientists thought the results looked more like a chemical reaction than a biological reaction.

“This is just an incredible scene…” (22)

“A new reality was created. Mars became a place. It went from a word, an abstract thought, to a real place.” (4)
The labeled release experiment showed the strongest results, detecting CO$_2$ that might have been released by the metabolism of microorganisms. The GC/MS experiment, however, indicated that no organics were present on Mars.

The results were unexpected... and confusing.

The scientists had to work quickly. The world was watching the scientific process in action, and the press and public were hungry for information. The researchers found themselves working under constant pressure and scrutiny.

"That's the ball game. No organics on Mars, no life on Mars." (4)

Some scientists argued that chemistry could explain the results of the Viking experiments, while others believed there was a chance for life on Mars.

"Having to work in a fishbowl like this is an experience that none of us is used to." (4)

By 1979, many scientists concluded that a chemical explanation for the results was the most likely. (24) The debate would continue, however, as new missions returned more detailed information about the environment of Mars.

"Some people thought life was more likely than other people thought, but I think what bound us together was the importance of the question, including the importance of negative answers." (4)
"Exobiology was tied to the planetary missions. It hung on the Viking program." (4)

After all the time and effort spent on Viking, and with many questions left unanswered, where was Astrobiology headed?

Viking didn’t find unambiguous signs of life on Mars, but it made people wonder if we had devised the right tests. Astrobiologists today are still trying to answer this question...

In 1988, the Soviet Union (and international partners) launched Phobos 1 and 2. Only Phobos 2 made it, and gathered data about Mars’ moon Phobos.

Phobos 2 fell silent...

...just before sending landers toward the moon.

After Phobos, Mars seemed to shroud itself in mystery.

Both the Soviet Union and the United States struggled with their missions.

In 1992, NASA launched the Mars Observer, but the excitement of returning to Mars was short-lived. On August 22, 1993, Mars Observer lost contact with Earth before entering orbit.

By the mid-1990s, political changes saw the dissolution of the Soviet Union, but Russia forged ahead with the Mars 96 orbiter and lander mission.

Unfortunately, the launch of Mars 96 proved unsuccessful and the spacecraft ultimately burned up on re-entry into the Earth’s atmosphere.
On November 7, 1996, NASA launched the Mars Global Surveyor (MGS). Some of the instruments that MGS carried were originally designed for the failed Mars Observer. MGS was a success! The mission returned data that covered the entire martian surface and helped astrobiologists learn more about the role of water and dust on Mars.

The MGS camera recorded weather patterns and discovered gullies and debris flows, suggesting that liquid water sources were once present at or near the surface of Mars.

Viking proved that we didn’t yet know enough about life on Earth to search for signs of life on another planet. Instead, scientists decided to study the environment of Mars, both past and present, to determine if the planet was ever habitable for life as we know it.

A key requirement for life on Earth is liquid water—so the search for life in the Solar System focused on searching for environments where liquid water is (or was) present.

For instance, MGS images from 2004 and 2005 were used to identify the formation of new gully deposits in the Centauri Montes region. These deposits look like they could have been made by running water... meaning liquid water might still flow on Mars today. (27)

In 1997, NASA launched Pathfinder. Unlike Viking, this mission did not carry instruments to search for life. Pathfinder did, however, demonstrate that a low-cost mission to Mars was possible. Pathfinder tested important technologies for future visits to the red planet, including...
...but many of the lessons learned were valuable to astrobiologists.

“The Pathfinder science results hinted at a warmer and wetter past for Mars.”
- Matthew Golombek, Pathfinder project scientist (28)

Among other things, the Pathfinder rover discovered round pebbles that looked as if they had been shaped by running water on the surface long ago.

This finding was evidence that Mars was once warm enough for liquid water to exist—maybe even for long periods of time. Even if Mars has no life today, maybe the planet could have supported life in its past...

Golombek: “In cases like Pathfinder, taking a little risk can result in an enormous payoff.” (28)

On July 3, 1998, Japan became the next country to attempt a visit to Mars. The Nozomi spacecraft was designed to capture images of Mars’ surface and to study the martian atmosphere and its interaction with the solar wind.

Nozomi failed to enter orbit around Mars, but kept orbiting the Sun so that it could try again in 2003.

However, when Nozomi approached the Earth for a gravity assist in April of 2002, the spacecraft was damaged by powerful solar flares. In December 2003, the mission was abandoned, and Nozomi changed course to avoid a collision with Mars.
NASA's next visits to Mars were also fraught with difficulty. First was the Mars Climate Orbiter, which was designed to search for evidence of past climate change on Mars. When the spacecraft reached Mars, it entered an orbit too close to the planet and atmospheric stresses tore it apart.

A success finally came on October 24, 2001, with NASA's 2001 Mars Odyssey mission. It's now the longest-lived mission to study a planet other than Earth from orbit. Odyssey's maps of hydrogen in particular helped scientists discover vast amounts of water ice just beneath the surface at Mars' poles.

Next, the Mars Polar Lander tried to land in the southern Planum Australe region, near the carbon dioxide ice cap at the martian south pole. The lander was going to analyze polar deposits and soil samples for the presence of water ice. NASA lost contact with the spacecraft as it began its treacherous descent toward Mars.

Odyssey has mapped the chemical elements and minerals that make up the martian surface, providing essential information about the martian environment and the potential for past or present life on the planet. Odyssey has also recorded radiation levels on Mars in order to determine the potential risks to future human explorers.

Today, Odyssey is still mapping martian minerals and is now part of a communications relay that allows scientists to 'talk' with other Mars missions. Odyssey is sure to play an important role in the future exploration of Mars.
On June 2, 2003, the European Space Agency (ESA) launched the Mars Express mission, adding to the international community of robotic explorers at Mars.

Mars Express was a huge success and continues to return valuable data. (34) The orbiter has captured images of craters, volcanoes and other features in high resolution.

Mars Express has also identified mysterious evidence of methane gas in the atmosphere of Mars. Some scientists believe that this methane may be produced by living organisms beneath the martian surface.

Unfortunately, the Beagle 2 lander was lost during its descent toward Mars.

The mission also carried the Beagle 2 lander, which was the first mission since Viking designed specifically to look for evidence of past or present life.

"The Beagle 2 project was based on martian meteorite studies. I think the real thing that is driving us back to wanting to look at whether there is life on Mars... is something that Viking did that nobody anticipated, nobody planned. It was that they were able to show that we have martian meteorites on Earth." (33)

"Mars Express is the first fully European mission to any planet. It is an exciting challenge for European technology." - Rudi Schmidt, Mars Express Project Manager (32)

Mars Express was designed to re-launch some instruments that were lost on the Russian Mars 96 mission. (33) One of its primary goals was to determine what happened to the water that once flowed on the planet’s surface.

Colin Pillinger, Beagle 2 Chief Scientist.

Mark Sims, Beagle 2 Mission Manager

Mission scientists scoured images taken by orbiters for any sign of Beagle 2...

...but eventually Beagle 2 was declared lost.
In 2003, NASA launched another tremendously successful mission to Mars—the twin Mars Exploration Rovers. After landing on Mars in January of 2004, the Mars Exploration Rovers Spirit and Opportunity had many adventures.

Spirit landed three weeks before Opportunity on a broad plain in Mars’ Gusev crater. Spirit discovered that most of Gusev’s geology is volcanic in origin, although the rover did eventually find some evidence of past liquid water.

On the other side of the planet, Opportunity had a “hole in one” landing, bouncing across the flat Meridiani Plains directly into tiny Eagle crater.

Opportunity’s first image from Mars was of the crater’s wall, a cross-section punched through the martian surface eons ago by a meteorite. This outcropping allowed the rover to see many years of geologic history in one glance.

Some rocks in Eagle crater had odd, round balls that scientists nicknamed “blueberries.”

Opportunity traveled many kilometers beyond its landing site inside Eagle crater.

The rover discovered that they were spheres of hematite. Geologists say the hematite most likely formed long ago as a result of water-saturated soil.

It viewed wispy martian clouds, providing scientists with images of martian weather from the ground.
Both rovers became mired in fine, loose soil at different times. To avoid getting stuck, the rovers had to be moved only centimeters at a time over several weeks.

Sometimes the hazardous soil provided welcome surprises.

Dust devils can’t lift a rover, but they did sweep dust from the solar panels. This helped keep the rovers powered and operating well beyond their mission lifetime of 3 months.

Opportunity continued to clock astonishing distances across the surface of Mars, turning up many unexpected discoveries…

Opportunity even dared to venture down the steep walls of Endeavor crater.

It was a dangerous trip, and many people thought there would be no return.

But inside the crater was a massive wall of exposed rock that could provide many clues about the ancient history of Mars’ climate. The mission team decided the risk was worth it.

Opportunity did make it safely out of Endeavor to continue its mission. Spirit fell silent in the spring of 2010.

The MER rovers made good use of their rock abrasion tools, or RATs…

…allowing scientists to see what lay hidden beneath Mars’ hard, exposed surfaces.

The MER rovers also encountered dust devils, mini tornadoes that sweep across the martian surface.

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Opportunity continued to clock astonishing distances across the surface of Mars, turning up many unexpected discoveries…

…like fallen meteorites resting on the vast Meridiani Planum.

Spirit’s wheels churned up salts when driving through one such area—the same kind of salts that form on Earth when hot springs mix with volcanic rock.

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On August 12, 2005, NASA added the Mars Reconnaissance Orbiter (MRO) to the network of martian missions.

MRO was loaded with powerful instruments, including a shallow radar to ‘look’ under the surface of Mars.

MRO is studying whether or not liquid water was present on the surface for long periods of time. (38) Other missions found evidence of flowing water, but was it around long enough for life to evolve?

In November of 2006, NASA received the final signal from the Mars Global Surveyor—after the spacecraft’s decade of hard work (Page 11). (39)

“When we watched the launch 10 years ago, we wondered if we would make the specified mission length. We certainly were not thinking of a 10-year operating life.” (40)

“It is an extraordinary machine that has done things the designers never envisioned despite a broken wing, a failed gyro and a worn-out reaction wheel. The builders and operating staff can be proud of their legacy of scientific discoveries and key support for subsequent missions.” (39)

After the final bow of MGS, NASA began a new mission based around the failed Mars Polar Lander (see page 13).

On August 4, 2007, the Phoenix Mars Lander launched toward the red planet. ESA’s Mars Express later helped track the mission as it made the dangerous journey down to the surface of Mars.

With a successful touchdown on May 25, 2008, Phoenix became the first lander to explore Mars’ northern polar region.

Phoenix searched for evidence of past or present water, as well as other chemical elements that may be necessary for life.

Phoenix set out to answer questions like: “Can the martian arctic support life?” and “What is the history of water at the Phoenix landing site?” (43)
Smooth, bright patches seen beneath the lander were thought to be ice that was uncovered when thruster exhaust blew off loose soil.

Phoenix became the first mission to touch water ice layers underneath the surface when it started digging with its robotic arm.

Clumps of bright material that were spotted in the trenches disappeared over 4 days, implying they were water ice rather than carbon dioxide ice (which would have vaporized faster).

Phoenix also used its arm to scoop soil into its instruments. During the initial heating cycle of one sample, Phoenix’s Thermal and Evolved-Gas Analyzer (TEGA) detected water vapor. Phoenix also found calcium carbonate, which suggests the occasional presence of thawed water.

When capturing pictures of one of Phoenix’s legs, scientists spotted what appeared to be water droplets that grew over time... liquid water droplets.

This was completely unexpected. Scientists have theorized that liquid water cannot exist on the surface because of Mars’ thin atmosphere and frigid temperatures.

Some scientists think that the temperature of Phoenix’s leg and the presence of salts may have caused water vapor to condense from the air. The question remains unanswered...

Perchlorate salts could have implications for water on Mars. For instance, in soil above ice, the salts could act as a sponge and might support habitats for life.

Phoenix ceased communications in November 2008 as the martian winter set in. No contact was made after the spring thaw. Orbiting spacecraft showed that Phoenix was crushed by frost accumulation.
Opportunity wasn’t alone for long. NASA was already preparing a new Astrobiology mission. The Mars Science Laboratory (MSL) was the first roving analytical laboratory sent to Mars. When it launched, the rover’s suite of instruments were the biggest and most advanced scientific package ever sent toward the martian surface.

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In 2011, mission components for MSL were processed for planetary protection and installed on the Curiosity rover. With everything packed away for launch, MSL successfully began its journey on November 26, 2011. (51-53).

The MSL rover received its name from a sixth-grade student in Kansas, named Clara Ma. Clara dubbed her, “Curiosity.” (54)

The MSL spacecraft safely entered its cruise phase, and Curiosity traveled inside for the eight and a half month journey.

En route, Curiosity used its RAD instrument to study space radiation between the Earth and Mars.

There were massive solar storms in early 2012...

...and Curiosity measured how much radiation future explorers, both robotic and human...

...might endure on a trip to Mars.

“Curiosity is an everlasting flame that burns in everyone’s mind.” (55)

“Curiosity is the passion that drives us through our everyday lives. We have become explorers and scientists with our need to ask questions and to wonder.” (55)

“RAD was designed to characterize radiation levels on the surface of Mars, but an important secondary objective is measuring the radiation during the almost nine-month journey...” (56)

Don Hassler, RAD Principal Investigator
The radiation was no real hurdle for Curiosity. The real challenge came during its arrival at Mars...

...seven minutes of terror before touching down on the surface!

The descent stage took Curiosity into the martian atmosphere.

With its heat shield as protection, the craft plowed through the atmosphere!

At roughly 240 seconds, a parachute was released!

The rover then drifted down toward its target—the enormous Gale Crater.

At an altitude of about 1.8 km, Curiosity separated from its shell.

After 345 seconds, the rover dropped from the shell and a powered descent stage brought it closer to the surface.
When Curiosity was just 20 meters above the ground, the ‘sky crane’ system gently lowered the rover to a soft landing.

By pointing the sky crane’s jets outward, the landing site was protected from any contamination from their exhaust.

Finally, the powered decent module flew away, leaving Curiosity on a pristine site inside Gale Crater.

As Curiosity carefully worked its way up the mound, layer by layer, it collected data about what Mars’ environment was like in the past, how it changed with time...

... and whether or not the red planet could have supported life.

Gale Crater was chosen as a landing site because it has a huge mound in the center of layered materials deposited over time. At the bottom of the layers are clay minerals. On top of the clay are layers containing sulfate minerals that are known to form in water.

All of Curiosity’s instruments play a role in finding targets for research and collecting data.

First, Curiosity’s camera ‘eyes’ (MastCam)...

...are on the lookout for interesting features on the surface.

Curiosity can then use its other remote instrument, ChemCam, to fire laser pulses at rock and soil samples...

MastCam helps astrobiologists on Earth spot science targets on Mars.

...up to 7 meters away!

Interesting...
The energized atoms and ions blasted off the rock are then analyzed in order to determine the elements, such as oxygen and silicon, that are present in the sample.

Next up are the contact instruments.

If the target still seems interesting to astrobiologists, then it’s time for Curiosity to use its drill and collect a sample!

Curiosity drives close and uses the MAHLI to take close-up pictures.

APXS then determines the sample’s elemental chemistry, from major elements down to trace elements.

Curiosity’s arm then transports the material to the rover’s onboard analytical laboratory, SAM and CheMin.

SAM is actually a suite of three different instruments, a Quadrupole Mass Spectrometer (QMS), a Gas Chromatograph (GC), and a Tunable Laser Spectrometer (TLS).

SAM then cooks the samples and analyzes the gases that are released.

Each of these advanced scientific instruments has a turn analyzing the sample.

When the samples are processed and delivered to SAM, they are deposited and sealed in one of 74 sampling cups that rest inside a special oven.

Together, they allow SAM to study chemistry and search for organic compounds.
Samples are also delivered to CheMin.

This mineralogy instrument determines what the rocks are.

CheMin studies how water may have affected the formation, deposition, or alteration of the minerals.

Together, SAM and CheMin are unlocking hidden secrets in the tiny particles of martian sand and dust.

It didn’t take long for Curiosity to astonish astrobiologists.

The rover found rounded pebbles that were evidence of an ancient stream bed.

One region, known as Yellowknife Bay, had all the trademarks of an environment that would have once been habitable for life as we know it.

“At a minimum, the stream was flowing at a speed equivalent to a walking pace—and it was ankle-deep to hip-deep.” (59)

“Our mission is turning a corner.”

“We are beginning to map a way forward, a way to explore deliberately for organic matter.” (60)

Rebecca Williams (The Planetary Science Institute)
On November 18, 2013, NASA launched the Mars Atmosphere and Volatile Evolution mission, or MAVEN. Scientists think Mars had a thick atmosphere and water at the surface. Early Mars could have been as habitable as the early Earth. "Where did the water go?!"

MAVEN is using its instruments to investigate a planetary mystery. When the inner planets first formed, Mars wasn’t much different than Earth. But then something happened... ...leaving Mars as the cold, desert world we know today.
A likely culprit for this transformation is the Sun.

Radiation and solar wind gradually blasted much of the martian atmosphere away.

Unlike Earth, Mars no longer has a powerful magnetic field to protect its atmosphere.

MAVEN is the first dedicated mission to study how atmospheres escape into space, and the data from Mars could also help astrobiologists understand Earth’s atmosphere and habitability.

Curiosity is also helping MAVEN...

The rover found heavy isotopes of gases in the atmosphere, indicating that the lighter ones have indeed escaped to space over time.

This cooperation between MAVEN and Curiosity is just the beginning of the next phase in Mars exploration.
“We now believe that Mars preserves a record of habitable environments, some of which may be active today. Our next step will be to determine whether or not life ever started on Mars.” (53)

“Considering how long the Spirit and Opportunity rovers have lasted beyond their design lifetimes, it almost boggles the mind to think how long MSL could last. It may be there to greet the astronauts when they arrive on Mars.” (52)

“With its sophisticated instruments, MSL is the first astrobiology mission since Viking.” (61) (53)
In September of 2014, the Indian Space Research Organization’s (ISRO) Mars Orbiter Mission (MOM) joined the team at Mars. MOM collects thermal emissions from the surface during both day and night.

Next up was the NASA lander, InSight**, launched in 2018. InSight set down on Mars and is studying the planet’s deep interior. Whether or not Mars is still geologically active beneath the surface is a big question. Studying the martian interior will help astrobiologists understand the processes that shape rocky planets.

The first mission in the joint ESA/Roscosmos ExoMars* program arrived in orbit in 2016. The Trace Gas Orbiter (TGO) is studying gases in the atmosphere that are only present in small amounts. TGO also tested European technology for a future landing on the surface.

**Interior Exploration using Seismic Investigations, Geodesy and Heat Transport

In 2018, after an incredible 15 years and 45.16 km, Opportunity sent its last message home to Earth. The MER mission was complete, but astrobiologists will be working with data from the twin rovers for decades to come.

When Spirit and Opportunity took their final bow, they left Mars a much busier place than when they first arrived.

*Exobiology on Mars
A large team of robotic explorers are now actively at work on the planet and in orbit.

This team of adventurers continues to grow as scientists develop new technologies for Mars missions.

As Curiosity touched down on Mars, NASA scientists were already designing and building new instruments.

NASA helped in the development of the Mars Organic Molecule Analyzer (MOMA), to launch on the next European mission.
The second mission of the ESA/Roscosmos ExoMars programme is ExoMars 2022. This mission will deliver a stationary science platform and a rover that carries a powerful drill. The rover is named for a key figure in the history of astrobiology, Rosalind Franklin (See Issue 1).

Rosalind Franklin will use its drill to retrieve pristine samples from as deep as two meters below the martian surface.

NASA contributed to the mission by building the mass spectrometer and other components for the rover’s MOMA instrument.

MOMA is central to the mission and will detect, identify, and quantify organic matter that might be present in samples.

Rosalind Franklin (1920-1958)

In 2020, more countries are joining in Mars exploration for the first time: China and the United Arab Emirates (UAE).

China’s Tianwen-1 aims to deliver a rover and orbiter in one mission.

Among the rover’s science instruments is a radar that will look for pockets of water beneath Mars’ surface.

The UAE’s Hope Mars orbiter will study weather on Mars and will gather data about how and why Mars’ climate has changed so dramatically through time.
The rover will extend its arm and use the SHERLOC* instrument in tandem with the WATSON** camera to map minerals and organic molecules in detail.

** Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC)

** Wide Angle Topographic Sensor for Operations and eNgineering (WATSON)

The Sample Caching System drills into Mars rock to collect samples.

The samples are moved through the rover’s body and photos are taken.

Then the samples are sealed in the Sample Caching System.

Finally, samples are passed to the Sample Handling Arm in the rover’s belly and stored.

The rover carries 43 sterile sample tubes in total.

For astrobiologists, the answers to questions about Mars’ habitability are in Perseverance’s ‘hands.’

...but, clumps of organics on certain parts of a rock could indicate life was once present.

Organic molecules are the carbon-based building blocks of life, but they are not necessarily made by biology...

The arm then transfers samples to a ‘bit carousel’ in the rover’s body.

Rosalind Franklin (1920-1958)

Mitch Schulte (NASA HQ), Mars 2020 Program Scientist.

NASA’s next trip to Mars is with the Mars 2020 mission and its rover, dubbed Perseverance.

Perseverance is an advancement on the capabilities of Curiosity, with upgraded hardware and new instruments.

Scientists will use data gathered by the rover at its landing site in Jezero crater to study the potential habitability of past environments.

Perseverance is also the first rover designed to seek possible signs of past Martian life.

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NASA’s next trip to Mars is with the Mars 2020 mission and its rover, dubbed Perseverance.
Perseverance will not study everything it picks up. Some samples will remain sealed and the rover will deposit a ‘cache’ of these samples at a specific location...

The mission is also testing technology that will pave the way for future missions, including a Mars Sample Return.

Perseverance has a total of 23 cameras and 7 science instruments. These tools will be used by many NASA scientists in addition to astrobiologists.

The rover will explore Jezero crater, filling its sample tubes with material from interesting spots.

This is the most complicated mechanism ever built and tested for spaceflight.

A Mars Sample Return could allow astrobiologists on Earth to examine pieces of present-day Mars up close...

...making it easier for a Mars Sample Return mission to come and collect them at a later date.

...and perform many experiments that are not yet possible with robotic explorers.
No one knows what the future of Mars exploration will bring...

...but for now, the planet is one of the most important locations beyond Earth for astrobiology.

The mission is also testing new technology like the lightweight Mars Helicopter - the first powered flight on another planet.

We have been systematically studying Mars for over 50 years, and are now getting to the point where we have the technology to really study Mars from an astrobiology perspective.

We’ve learned that Mars was habitable in the past, and we’re now getting down to the microorganisms’ level to see if there are traces that the planet had life in its past.

With a sample return, we could perform definitive studies by looking at aspects of samples that today’s missions can’t, like carbon isotope signatures and detailed organic matter searches.

With each new mission, Mars continues to be a major target for astrobiology research.

No one knows what the future of Mars exploration will bring...
Further Resources and References cited in this issue:

1. The background on this page is an image of M72: A globular cluster of stars captured by the Hubble Space Telescope. M72 is about 50,000 light years away and can be seen with a small telescope pointed in the direction of the constellation Water Bearer (Aquarius). This image shows about 100,000 of M72’s stars and spans about 50 light years. Credit: NASA, ESA

2. Harold “Chuck” Klein (First head of the Exobiology Division, NASA Ames Research Center)

3. L.P. “Pete” Zill (third head of Exobiology at NASA Ames)


5. Richard “Dick” Young (second head of Exobiology at NASA Ames; first head of the Exobiology Program at NASA Headquarters)


7. Cyril Ponnamperuma (Arrived at NASA Ames in the first class of postdoctoral fellows (summer 1961) (8)


11. Mariner 4 image, the first close-up image ever taken of Mars. The image is centered at 37ºN, 187ºW and is roughly 330 kilometers (km) by 1200 km. The resolution is roughly 5 km and north is up. Available from the NASA image archive at: http://nssdc.gsfc.nasa.gov/imgcat/html/object_page/m04_01d.html

12. Mariner 4 image, the first image to clearly show unambiguous craters on the surface of Mars. The area is roughly 262 km by 310 km and shows the region south of Amazonis Planitia at 14ºS, 174ºW. North is at roughly 11:00 in this image. Credit: NASA

13. This image of Venus was actually acquired by Mariner 10 during its flyby of the planet. Mariner 5 was built as a backup to the successful Mariner 4 mission, and its TV camera was removed when the craft was adapted for travel to Venus. Instead of photographing Venus, Mariner 5 probed the planet’s atmosphere with its suite of instruments. Credit: NASA/JPL

14. The cratered surface of Mars taken by Mariner 6. Image Credit: NASA/JPL

15. Mariner 7 had its closest approach to Mars at a distance of 3,524 km on July 31, 1969; after Mariner 6’s flyby. Image Credit: NASA/JPL

16. Mariner 9 view of the “labyrinth” at the western end of Vallis Marineris on Mars. Linear graben, grooves, and crater chains dominate this region, along with a number of flat-topped mesas. The image is roughly 400 km across, centered at 6ºS, 105ºW, at the edge of the Tharsis bulge. North is up. (Mariner 9, MTVS 4187-45). Credit: NASA/JPL

17. Mariner 9 image of the north polar cap of Mars. The image was taken on
October 12, 1972, about one-half martian month after summer solstice. At this time, the cap had reached its minimal extent. The cap is about 1000 km across. The interior dark markings are frost-free, sun-facing slopes. A smooth-layered sedimentary deposit underlies the cap. The image is centered at 89oN, 200oW. (Mariner 9, MTVS 4297-47). Credit: NASA/JPL

18. Mariner 10 oblique view of Wren crater and surroundings on Mercury. Wren crater is barely visible at the lower center of the image, containing a number of craters within its 215 km diameter floor. Running along the right side of the image is Antoniadi Dorsum. North is at 1:00. (Mariner 10, Atlas of Mercury, Fig. 2-10) (edge of planet). Credit: NASA

19. Mariner 10 image of Brahms Crater, Mercury. This image of the 75 km diameter crater was taken on the first flyby. Note the central peak. North is up. (Mariner 10, Atlas of Mercury, Fig. 3-2). Credit: NASA

20. Other missions in the Soviet Mars series were unsuccessful, including the lander attempt of Mars 7.


22. Dr. Thomas Mutch speaking to BBC News. Available at: http://news.bbc.co.uk/onthisday/hi/dates/stories/july/20/newsid_2515000/2515447.stm

23. The first image transmitted by the Viking 1 Lander from the surface of Mars on July 20, 1976. Credit: NASA Viking Image Archive


25. Viking 1 Camera 1 Mosaic of Chryse Planitia.
Credit: NASA Viking Image Archive

26. Light Deposits Indicate Water Flowing on Mars. This figure shows MGS images of the southeast wall of the unnamed crater in the Centauri Montes region, as it appeared in August 1999, and later in September 2005. No light-toned deposit was present in August 1999, but appeared by February 2004. Credit: NASA/JPL/Malin Space Science Systems


29. A false-color mosaic focuses on one junction in Noctis Labyrinthus where canyons meet to form a depression 4,000 meters (13,000 feet) deep. Dust (blue tints) lies on the upper surfaces and rockier material (warmer colors) lies below. The pictures used to create this mosaic image were taken from April 2003 to September 2005 by the Thermal Emission Imaging System instrument on NASA's Mars Odyssey orbiter. Credit: NASA/JPL-Caltech/ASU

30. Fans and ribbons of dark sand dunes creep across the floor of Bunge Crater in response to winds blowing from the direction at the top of the picture. This image was taken in January 2006 by the Thermal Emission Imaging System (THEMIS) instrument on NASA's Mars Odyssey orbiter. The pictured location on Mars is 33.8 degrees south latitude, 311.4 degrees east longitude. Credit: NASA/JPL-Caltech/ASU

31. This three-frame image shows a region in the southern highlands of Mars where Mars Odyssey found evidence of chloride salt deposits. These deposi-
its could point to places where water was once abundant, then evaporated, leaving the minerals behind. These images of the region were actually taken on March 30, 2007, by the High Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter. Credit: NASA/JPL-Caltech/University of Arizona/Arizona State University/University of Hawaii

32. European Space Agency. “Europe reclaims a stake in Mars exploration.” Available at: http://www.esa.int/SPECIALS/Mars_Express/SEMKR55V9ED_0.html


34. Astrobiology Magazine [www.astrobio.net], “Sounding Out Mars: an interview with Jeffrey Plaut.” Available at: http://www.astrobio.net/interview/1464/sounding-out-mars

35. Image taken by the Mars Express High Resolution Stereo Camera (HRSC) showing water ice on the floor of a crater near the Martian north pole. Credit: ESA/DLR/FU Berlin (G. Neukum)


37. This photo, taken by NASA's Opportunity rover, shows Mars' thin, diffuse clouds. Credit: NASA/JPL-Caltech


41. Details in a fan-shaped deposit discovered by NASA’s Mars Global Surveyor. Credit: NASA/JPL/Malin Space Science Systems

42. This is a shaded relief image derived from Mars Orbiter Laser Altimeter data, which flew onboard the Mars Global Surveyor. The image shows Olympus Mons and the three Tharsis Montes volcanoes: Arsia Mons, Pavonis Mons, and Ascreaus Mons from southwest to northeast. Credit: NASA


44. This image, one of the first captured by NASA’s Phoenix Mars Lander, shows the vast plains of the northern polar region of Mars. The flat landscape is strewn with tiny pebbles and shows polygonal cracking, a pattern seen widely in Martian high latitudes and also observed in permafrost terrains on Earth. Credit: NASA/JPL-Caltech/University of Arizona

45. Images from the Surface Stereo Imager camera on NASA's Phoenix Mars Lander shows several trenches dug by Phoenix. Credit: NASA/JPL-Caltech/University of Arizona/Texas A&M University


47. This HiRISE image shows the Phoenix lander after one year on Mars. The image is a close match to the season and illumination and viewing angles of some of the first HiRISE images acquired after the successful landing on May 25, 2008. The shadow that is cast by the lander is different than the previous year, indicating that Phoenix has suffered structural damage. Image Title: “Phoenix Lander after One Mars Year (ESP_017716_2485),” Credit: NASA/JPL/University of Arizona