What is ASTROBIOLOGY?

Astrobiology is the scientific study of the origin, evolution, distribution, and future of life in the Universe. The study of astrobiology brings together researchers from historically separate scientific fields such as microbiology, astronomy, geology, paleontology, and chemistry and encourages them to work together to answer the most fundamental questions science can pose: What is life? How did we get here? Are we alone in the Universe? How can we tell if we are?

These questions have been asked for generations, but it is only recently that we have had the technology and the knowledge to address them from a scientific perspective. Understanding the answers requires that researchers develop a larger perspective than is possible within any one field of science. Astrobiology is a collaborative effort, transcending the boundaries of traditional scientific disciplines.

Astrobiologists begin by studying life on Earth, the only place in the Universe where we know life exists. How did life begin here? How has it responded to changes in the environment? How has it changed the environment? What conditions does earthly life need to exist? The scientists of the NASA Astrobiology Program seek to answer these questions and many more.

The next step is to look beyond Earth to the possibilities of life elsewhere. Most life on Earth is microbial, and it's likely that microorganisms will be the type of life we will find elsewhere. Astrobiologists are figuring out how to search for signs of microbial life—past or present—on the planets and moons in our Solar System and beyond. How do you detect evidence of biology when you can't hold a soil sample in your hand? Does life leave its mark on a planet so that we can detect its presence remotely? Is life common? Or is our life-filled Earth rare and unique?

Life and Water

Astrobiologists also struggle with the question: what exactly does it mean to be alive? Life as we know it here on Earth exchanges energy and materials with the environment. Lifeforms grow, develop, produce waste products, and reproduce, storing genetic information in DNA and RNA and passing it from one generation to the next. Life evolves, adapting to changes in the environment and changing the environment in return. The basic unit of living things is the cell. Life is based on the chemistry of carbon and requires liquid water.

The "liquid" part is important. It's very hard to transport important substances like nutrients or metabolites from one place to another within a solid, and it's hard to control that transport in a gas. Liquids do it well.

Water has many qualities that make it an ideal medium for the cellular biochemical reactions necessary for life. The chemical properties of water molecules help the other molecules of life such as DNA, proteins (structural building blocks of cellular architecture and enzymes that speed up chemical reactions), and sugars (such as glucose, a common sugar used for energy), orient themselves in the proper three- dimensional shapes needed to carry out their functions in the cell. In order to maintain osmotic balance (and avoid drying out or swelling up), cells also need dissolved salts such as those of calcium and potassium. Water easily dissolves the nutrients and salts on which life depends and helps move these substances into and out of cells.

Water is the only chemical compound that is found naturally on Earth in all three physical states—gas, liquid, and solid. This property allows water to cycle through evaporation, condensation, and precipitation, between reservoirs in the oceans, on land, and in the air. Indeed, water is one of the few substances that can be liquid at the temperatures and pressures typical of the Earth's surface (mercury and liquid ammonia are the others). Water will remain liquid over an extremely large range of temperatures, freezing at 0°C (32°F) and boiling at 100°C (212°F). Adding salt will lower the freezing temperature, and adding pressure can raise the boiling point, increasing the range even more. Plus, it takes a lot of energy to raise the temperature of water a few degrees. All of which means that temperatures on Earth can undergo rather large variations before the liquid water freezes or boils away.

Much of the life on Earth depends on the water molecule for survival in another, fascinating way. Plants and many microorganisms such as cyanobacteria and algae carry out photosynthesis, the biochemical process of creating sugars and oxygen (O_2) from carbon dioxide (CO_2) in the air and light energy from the Sun. These reactions are dependent on the presence of liquid water, which is broken apart by the cell's molecular machinery during the process of photosynthesis. Those same microorganisms and plants can then consume the sugars they create, converting them to usable energy needed for growth and reproduction. Many other organisms such as animals (including humans!) later breathe that O_2 and consume those plants as food—generating CO_2 in the process—affecting a cycle and demonstrating how most life on Earth is linked to the Sun.

Life in Extreme Environments

On Earth, life is found virtually anywhere liquid water is present. Only in the past few decades have scientists realized that "anywhere" includes such extreme environments as thick ice sheets at the poles, hydrothermal vents on the ocean floor, and porous cracks in deep subsurface rocks. The organisms that live in these harsh conditions are called extremophiles. They survive in environments once thought too hot, too cold, too salty, too acidic, too high pressure, too dry, or with too much radiation for life to exist.

For example, scientists have long known that microbial mats (large colonies of microbes) are responsible for the beautiful colors observed in Yellowstone National Park's many hot springs. The water in these springs tops 90°C (188°F), much too

hot for us to touch. Some hot springs are also extremely acidic, with pH levels in a few cases similar to that of stomach acid. Yet life thrives in and around them.

In 1977, scientists were stunned to discover abundant life clustered around hydrothermal vents on the ocean floor thousands of feet below its surface. The vents form where the Earth's crustal plates crack and spread apart. Molten rock— magma—wells up along these cracks, forming long undersea mountain ranges known as mid-ocean ridges. Seawater seeps into the rock at the cracks, is heated, and shoots back upward through vents nearby, enriched with minerals dissolved from the rocks along the way.

Astrobiologists thought life would be impossible in the extremely hot temperatures (113-120°C, 235-248°F), oppressively high pressures (thousands of pounds per square inch), complete darkness, and toxic chemical brews typical near these ocean- floor vents. But microbes living there use chemical reactions involving hydrogen sulfide, common in the enriched seawater pouring out of the vent, to generate energy. Other creatures survive by eating the microbes, or each other. Should the flow of hot, enriched water slow to a trickle for any reason, the creatures around the vent would soon die.

Lifeforms discovered at hydrothermal vents include many species of microbes, mussels, clams, shrimp, and giant tubeworms that can reach ten feet in length. The tubeworms depend on symbiotic bacteria in their guts for their nutrition, a relationship that benefits both the worm and the bacteria. Hemoglobin in the worms' red tips grabs hydrogen sulfide from the water around the vent and transports it to the bacteria living inside the worm. Using this hydrogen sulfide as an energy source, the bacteria in turn convert carbon dioxide dissolved in the water into carbon compounds that nourish the worm.

Astrobiologists have also found bacteria in small pockets of liquid water embedded deep in "solid" lake ice in the McMurdo Dry Valleys of Antarctica. These valleys are among the coldest, driest places on Earth, with average temperatures of -20°C (- 4°F) and less than 10 cm (4 in) of precipitation a year. Small grains of dirt within the ice absorb sunlight to melt small amounts of the ice surrounding them, providing the liquid water needed to support life. The dirt also provides chemical nutrients for the bacteria that photosynthesize, grow, and reproduce in the liquid water pockets during the long Antarctic summer days.

The Rio Tinto in southwestern Spain is another interesting environment for life. The river has a deep red color—like red wine—because of iron dissolved in the water. It is highly acidic, with a pH of 2.0 in most of the river. The high acidity results from chemical reactions between the water and iron and sulfur minerals in the rocks around the river. Microbes living in the water also use the iron and sulfur minerals for chemical reactions that generate energy. Metabolic products from these reactions contribute to the low pH of the river. Numerous algae and fungi also thrive there.

Microorganisms living in groundwater 5 km (3 mi) below the surface in deep gold mines of the Witwatersrand Basin in South Africa have been recently discovered by a team of astrobiologists working there. These thermophilic (heat-loving) bacteria and archea thrive in cavities and cracks in rocks, living at temperatures that approach 80°C (176°F). They have diverse metabolisms, including sulfate reduction, a process in which sulfate is consumed and hydrogen sulfide is produced, as well as methanogenesis in which acetate or carbon dioxide is consumed and methane is produced. The same team of astrobiologists is also investigating life in the permafrost in the Canadian Arctic. These psychrophiles (cold-loving organisms) live at freezing cold temperatures around 0°C (32°F). Looking for subsurface life in permafrost regions will inform the development of tools to search for life in the subsurface of Mars.

"Extreme" vs. "Normal"

To extremophiles, the conditions in which they live are "normal" and "common." To them, the conditions we traditionally associate with life (moderate temperatures, sea level pressures, plenty of sunlight, an oxygen-rich atmosphere) are "extreme" and deadly. "Normal" and "extreme" are relative terms. Conditions that we think of as "extreme" on Earth may be similar to what is "common" elsewhere in the Solar System. Understanding how life survives in earthly extreme environments can help astrobiologists better understand how life could exist on other planets and moons.

One thing extremophiles have in common with the rest of us is that they, too require liquid water to survive. Consequently, when scientists think about non-earthly places where life may exist, they look for sites where liquid water either is now or was once at some time in the past.

Life on Mars?

Mars today is a frozen, dry world. Its predominantly carbon dioxide atmosphere is too thin to support liquid water on its surface, and its surface temperatures are too cold, averaging -65°C (-85°F). Yet its surface is covered with winding channels that resemble ancient riverbeds, and there is water ice frozen in the planet's polar ice caps and subsurface permafrost. Enormous extinct volcanoes indicate Mars was once tectonically active, even though its core is now too cold to support volcanic activity.

The observations of hematite "blueberries" from NASA's Mars Exploration Rover *Opportunity* indicate Mars once may have had a thicker, warmer atmosphere and liquid water standing and flowing on its surface. Could life have emerged at that time? Did it find a way to adapt, evolve, and survive the shift from moderate to extreme conditions?

NASA's rover *Curiosity*, which landed at Gale Crater on the Martian surface in August, 2012, is a miniature analytical chemistry laboratory. It is examining the surrounding landscape, including exposed sedimentary layers on Mount Sharp— rising 5.5 km (18,000 ft) high in the center of Gale Crater. Its largest instrument package, called Sample Analysis at Mars (SAM), is tasked with searching for compounds of carbon that are associated with life (like methane) and exploring their sources of generation and destruction on Mars. It is also taking inventory of other elements that may be associated with life, including oxygen, nitrogen, and hydrogen.

An Ocean on Europa?

Europa, a moon of Jupiter which is slightly smaller than Earth's Moon, is one of the smoothest objects in the Solar System. There is strong evidence that a liquid water ocean between 50 and 100 km (30-60 mi) deep surrounds Europa's rocky interior, and that the ocean is in turn covered by a layer of water ice a few kilometers thick.

Europa is deformed into a slightly oval shape by the gravitational pull of Jupiter and its orbit is made slightly non-circular by the gravitational pull of the other large moons, causing Europa to twist and flex as it orbits Jupiter. This tidal flexing has heated Europa's interior, accounting for the ocean under the ice. Cracks and streaks crisscross Europa's surface. Scientists think water may seep up through cracks in the ice caused by the gravitational twisting of the ice sheet, creating the streaks observed on the surface.

A curious analog to Europa's ice-covered ocean can be found in Antarctica. In 1996, scientists discovered evidence of a lake of liquid water about the size of Lake Ontario deep underneath the ice at Russia's Vostok Station, about 1,000 km (600 mi) from the South Pole. Dubbed Lake Vostok, the liquid water sits under roughly 3,700 m (12,000 ft) of ice and may have been isolated for millions of years. No one knows if there is any kind of life in Lake Vostok.

In February, 2012, Russian scientists successfully drilled down through the ice, and plan to collect water and sediment samples at the end of 2012 during the Antarctic summer. Contamination by earthly organisms in the drilling and sampling process is a concern not only for scientists at Lake Vostok, but for astrobiologists looking for evidence of life in our Solar System as well. Proven techniques for drilling without contamination will be invaluable when probes are sent to explore Europa and Mars.

Titan's Thick Atmosphere

Titan, Saturn's largest moon, is the only moon in the Solar System with a thick atmosphere. Methane clouds drift close to the surface and a thick smog of organic molecules floats 300 km (190 mi) above the ground. A thin haze high in the outer atmosphere completes the picture. These clouds and haze keep nearly all sunlight from reaching Titan's surface, which is a chilly -180oC (-292oF).

The Cassini spacecraft, a joint effort of NASA, the European Space Agency, and the Italian Space Agency, entered Saturn's orbit in 2004. The Huygens probe, carried by Cassini, plunged into Titan's atmosphere in early 2005, and landed safely on the ground two hours and 32 minutes later. The probe revealed striking images of drainage channels leading toward a lake shoreline, as well as small, smooth, rounded rocks not unlike river rocks on Earth. Although the processes at work creating the look and feel of Titan's surface are remarkably Earth-like, make no mistake—this is an alien world. On Titan it is so cold that water plays the role of rock and lava, and flowing methane carves river channels and fills great lakes with liquid natural gas, which also occasionally rains from the sky as water does on Earth. Vast regions of tall dunes stretch across the landscape—dunes whose "sand" is composed of dark hydrocarbon grains versus silicon dioxide here on Earth.

Cassini provided data to "lift Titan's veil," suggesting that Titan's interior may consist of a global ocean of liquid water and ammonia perhaps about 100 km (60 mi) beneath the surface sitting above a layer of high-pressure ice and a water-infused silicate core. It is also thought that Titan's thick atmosphere is replenished as it is lost to space by volcanic outgassing from the interior. Cassini mission's "Grand Finale" occurred in 2017. The next mission to explore Titan will be NASA's Dragonfly, the first mission to fly a science vehicle on another planetary body. Dragonfly is planned to arrive at Titan in the mid 2030s. It will explore the prebiotic chemistry, habitability, and potential for life on Titan.

Impact of Extremophiles

The extreme environments of Mars, Europa, and Titan may or may not host life. We do not yet know. Fortunately, scientists can use earthly extreme environments to test equipment and techniques they may someday use to search for life on these and other planets and moons. For example, astrobiologists have used remotely- controlled equipment to drill into the rocks under Spain's Rio Tinto, as subsurface conditions there may resemble those on Mars where underground liquid water could exist amid rocks rich in sulfur and iron. There is also a team of astrobiologists testing a "lake lander" in the highest lakes on Earth—in the Chilean Andes—and developing an adaptive system that could someday help us learn more about the lakes on Titan.

Earthly extremophiles have forever changed our view of life and the conditions life needs to survive. Their existence has proven that life can exist in a broad range of environments. They have allowed astrobiologists to expand their ideas of where to look for life. It is not enough to know only about biology when looking for life. Life on other worlds could certainly leave signatures for us to detect, but these will likely go unnoticed without the collaboration of biologists, geologists, astronomers, and others. Astrobiology provides the umbrella under which scientists trained in these and other fields collaborate to understand life here on Earth as well as the possibilities of life elsewhere in the Universe.