Life in the Solar System and the Universe

It was once assumed that Earth was just a typical planet in a run-of-the-mill solar system. Some evidence is beginning to appear that suggests this isn't true. If so, what does this mean about life on other planets?

Sci-fi movies since the 1950's have shown invaders from other planets coming to attack Earth. Captain Kirk of *Star Trek* made a career out of seeking out new life forms and new civilizations. "Contactees" swear they have been kidnapped by aliens visiting our planet. In the public mind, the galaxy seems to be swarming with life, especially intelligent life. How much do we really know scientifically about the chance that life exists on other planets, however? And if life exists apart from Earth, is any of it intelligent?

The first man to try and put this question on a scientific basis was Frank Drake. Drake was an astronomer who wondered whether it would be possible to discover other intelligent life by using radio waves. Drake knew since the invention of radio in the early 20th century, mankind had been accidentally announcing its existence to the rest of the galaxy by signals from its radio and TV stations. He reasoned if others could detect Earth from its radio waves, it must be possible for Earth to detect other intelligent civilizations by listening for their electronic emissions.

The Drake Equation

Drake and other scientists at the time were interested in searching the skies for other intelligent life. Spending the money to do this, however, would only make sense if there was a reasonable chance that there was a civilization nearby that was technologically-advanced enough to use radio waves, but how could you figure out how many civilizations might be broadcasting at any particular time? In 1961, Drake came up with an equation he thought might give him an answer. First, Drake decided to limit the area of his inquiry to our own galaxy: The distances between galaxies is so great that even at the speed of light it would take many thousands, perhaps even millions, of years for radio signals to travel the distance between, and when they arrived, they would be extremely faint.

The equation Drake produced multiplied a number of variables together (for example, the number of stars in the galaxy times the fraction of stars that are "sun-like") to get an answer. The results, though, were highly dependent on the value of the variables entered. Some were well-known and accepted values, like the number of stars in the galaxy, while others weren't much more than wild guesses (like the number of years a technological civilization might exist before going extinct).

Various scientists have used the equation over time and have gotten a variety of answers. The most optimistic result is that there are several billion civilizations in our galaxy. The most pessimistic estimate is about 100. Many scientists feel comfortable with a figure of million radio-using civilizations. The more optimistic figures have been used to justify SETI (Search for Extraterrestrial Intelligence) projects where receivers search the sky for signs of artificial, extraterrestrial radio sources. Even with as many as a million radio-capable civilizations in our galaxy at this moment, however, it might be hard to detect one from Earth. Because those million civilizations are spread over a galaxy that contains 300 billion stars, it is unlikely that any are very close to our position.

One characteristic of the Drake formula is that it multiples all the values together to get the estimate. This means if any of the variables approaches zero (a value can never be zero itself because we know that at least one radio using civilization exists, ours) it can drive the results, the number of radio-capable civilizations in the galaxy, to a very low value. Perhaps even a value of one.

Key Factor: the Moon

One of the key values in the equation is the fraction of planets suitable for life where life actually develops. In the past this was often set to a value of one. This means that scientists expect that for every planet where the conditions are suitable for the development of life, life is very likely to develop. This may not be the case, however. Many scientists considered Earth to be a typical "rocky" planet. Nothing significantly special about it. After all, with all the millions of planets in the galaxy, what are the chances that ours was somehow unique?

There is, however, something very unusual about Earth that may profoundly affect the establishment of life. It is the moon. No other planet in our solar system has a natural satellite that is nearly as big in relationship to itself. Most moons are thought to have either formed out of leftover material from the creation of their mother planet or were asteroids captured by the mother planet's gravity. Not so our moon. The leading theory suggests that sometime early in Earth's history, a large body, perhaps near the size of Mars, was orbiting the sun in a highly-elliptical orbit. The path of the body, or planetesimal, took it across earth's nearly circular orbit. They avoided each other for many millions of years, but at some point they collided.

A collision like this was not that unusual in the early solar system. What was extremely unusual about the impact was the angle at which the planetesimal struck. It nearly bounced off. This strange angle was to be a key factor in what happened next. The violence of that impact can hardly be imagined. An explosive force equal to a billion, trillion, tons of TNT would have been unleashed. Five billion cubic miles of the earth's outer primordial crust were blown off the surface. Because of the angle of the impact, however, the material neither fell back to earth nor was blown into interplanetary space. Instead, it went into orbit, forming an enormous ring around our planet not unlike those we now see around Saturn. Over time the bits of rock in that ring, under the influence of gravity, coalesced into the moon. The moon was originally ten times closer to Earth than we see it. Over time the moon moved outward to its current position.

Having such a large moon has profoundly affected our planet,. most obviously through extremely strong tidal forces. The gravity of the moon drags the waters on the surface of earth towards it to give us our low and high tides. The tides, in turn, affect our planet. Originally (when the earth formed) it probably rotated once every six hours. Tides have slowed this down to one rotation every 24 hours. If there were no moon, the earth's ocean would still have tides caused by the gravity of the sun, but these would be much weaker. It is estimated that a moonless earth with weaker tides would rotate every eight hours.

Drake's equation assumes that life evolves under the right conditions, but do these conditions require tremendous tides that mix the seas into a chemical brew? Perhaps. Almost all scientists who accept that if life on earth came into being though evolution, agree the process would have taken much longer without the strong tides caused by the moon.

Typical Planetary System

At the time that Drake came up with his equation, scientists knew nothing about planetary systems other than our own. No extra-solar planets had ever been found. In the last ten years, however, astronomers have used a number of clever techniques to detect distant planets circling far away stars. At this point in time, well over a hundred planetary systems have been found. None of them seem to resemble ours, however. Most have large, giant, gas planets in tight orbits around the central star. This is unlike our system which has a number of "rocky" planets close to the star and gas giants further out. Also, the giant planets seem to have a much more elliptical orbit than the planets in our system, which might generate extreme temperature changes on those worlds.

So far, our astronomical instruments are not precise enough to detect anything as small as a terrestrial-type planet circling a distant star system, so perhaps they are out there somewhere. However, the differences we do see may indicate that most star systems formed differently than ours did. If so, this might well indicate that the number of earth-like planets per star system is much smaller than once thought. This will also affect the results of Drake's equation.

Life in our Galaxy

So are we alone? Evidence seems to be mounting that instead of being typical, the earth and our solar system are very unusual. However, this does not preclude life developing somewhere else under completely different circumstances. Systems containing only gas giant planets may develop life on the moons of those planets.

In our own solar system Europa, a moon of Jupiter, is considered a possible haven for primitive life as well as Titan, a moon of Saturn. Both Europa and Titan are probably too far from the warmth of the sun to develop any kind of advanced life, but what about moons circling gas giant planets close to their stars in other solar systems? Would the mother planet of the stars provide the necessary tidal forces to accelerate life? Perhaps some kind of life can also exist in the clouds of those gas giant planets. Picture a colony of huge jelly-fish-like animals floating though the alien sky. Even stranger possiblities exist. The late Robert Forward, a scientist and science-fiction writer, suggested in his novel *Dragon's Egg* life might even be able to exist on the surface of a neutron star, though such life would be radically different than our own. As we venture out beyond our solar system, we should be prepared to find life, but it may be far different than the little gray men with large eyes we so often picture in our minds. Far different and much, much rarer.

The Drake Equation Mathematical Presentation

The Drake Equation is developed to estimate how many intelligent, communicating civilizations there are in our galaxy. The Drake Equation is**:** **N = N* fp ne fl fi fc fL**

The equation can really be looked at as a number of questions:

N* represents the number of stars in the Milky Way Galaxy

Question: How many stars are in the Milky Way Galaxy?

Answer: Current estimates are 100 billion.

fp is the fraction of stars that have planets around them

Question: What percentage of stars have planetary systems?

Answer: Current estimates range from 20% to 50%.

ne is the number of planets per star that are capable of sustaining life

Question: For each star that does have a planetary system, how many planets are capable of sustaining life?

Answer: Current estimates range from 1 to 5.

fl is the fraction of planets in **ne** where life evolves

Question: On what percentage of the planets that are capable of sustaining life does life actually evolve?

Answer: Current estimates range from 100% (where life can evolve it will) down to close to 0%.

fi is the fraction of **fl** where intelligent life evolves

Question: On the planets where life does evolve, what percentage evolves intelligent life?

Answer: Estimates range from 100% (intelligence is such a survival advantage that it will certainly evolve) down to near 0%.

fc is the fraction of **fi** that communicate

Question: What percentage of intelligent races have the means and the desire to communicate?

Answer: 10% to 20%

fL is fraction of the planet's life during which the communicating civilizations live

Question: For each civilization that does communicate, for what fraction of the planet's life does the civilization survive?

Answer: This is the toughest of the questions. If we take Earth as an example, the expected lifetime of our Sun and the Earth is roughly 10 billion years. So far we've been communicating with radio waves for less than 100 years. How long will our civilization survive? Will we destroy ourselves in a few years like some predict or will we overcome our problems and survive for millennia? If we were destroyed tomorrow the answer to this question would be 1/100,000,000th. If we survive for 10,000 years the answer will be 1/1,000,000th.

When all of these variables are multiplied together when come up with:

N, the number of communicating civilizations in the galaxy.

To read more about the Drake Formula, go to http://www.astro.indiana.edu/drake/intro.swf

SETI

If we are leaking radio messages into space, the inhabitants of other planets, if they exist, might be doing the same thing. Large radio telescopes on Earth could detect such radio leaks from civilizations in nearby star systems, as well as stronger signals dispatched from planets thousands of light years away.This realization is the keystone of SETI — the Search for Extraterrestrial Intelligence. SETI is an effort to locate evidence of past or present communicative civilizations in the universe, particularly within our own galaxy. (The Drake Equation provides one way to make a rough estimate of how many such civilizations exist.) The idea of searching for extraterrestrial life has been dreamed of through the ages, but the spark behind contemporary methodology began in 1959 when two physicists from Cornell asserted that microwave radio waves could be used for interstellar communication. One year later, young astronomer Frank Drake (who later became president of the SETI Institute) began his own microwave radio search throughout the galaxy. Drake pointed an 85-foot antenna towards two Sun-like stars and analyzed the reception for two months. The antenna didn't pick up any unique frequencies, but the project inspired a new generation of SETI scientists.A decade later, NASA established a SETI program. It continued until the early 1990s, when SETI funding was cut after being ridiculed on the floor of Congress as a search for "little green men." Since then, the SETI Institute, a non-profit corporation, has taken over the search, as have several other privately-funded SETI projects. (No public money is being spent on SETI today.)

The Habitable Zone

From the center of the Earth to the far-flung galaxies, we find evidence that life arose from cosmic processes. The iron in our blood and the calcium in our bones was made inside stars. All silver and gold was forged by stars that exploded long ago. Terrestrial life is embedded in a cosmic web, and it seems reasonable to speculate that life is cosmically commonplace.

If life is in fact cosmically commonplace, where might we find it? Our search begins within the solar system, as we try to locate three ingredients upon which life depends: water, energy, and organic molecules (or carbon). Recent discoveries inform us that these requisites may exist well beyond the planets closely orbiting the sun. This area — where conditions might potentially support life — is called The Habitable Zone.

One of the main ingredients for life as we know it is liquid water. Water exists as a liquid between 273K and 373K (unless the pressure is too low, in which case the water sublimates into gaseous water vapor). The region on the solar system (or any planetary system) where the temperature is in this range, is called the **habitable zone**.

The habitable zone first encompassed the orbits of Venus to Mars, planets close enough to the sun for solar energy to drive the chemistry of life — but not so close as to boil off water or break down the organic molecules on which life depends.

But the habitable zone may be larger than originally conceived. The strong gravitational pull caused by large planets may produce enough energy to sufficiently heat the cores of orbiting moons. Life has proven itself tough here on Earth. Perhaps it could thrive in more extreme environments.

As stars evolve on the main sequence, they become brighter and hotter. This makes the habitable zone move out with time. The Sun is now some 30% brighter than it was 4 billion years ago, and will eventually double that brightness before evolving off the main sequence. In the figure at left, the habitable zone moves outward between times t_0 and t_1. The region labeled CHZ is the continuously habitable zone. About 4 billion years ago, Venus was located near the inner edge of the habitable zone; today it lies closer to the Sun than the inner edge of the habitable zone.

UFOs

Since June 24, 1947, the day American pilot Kenneth Arnold reported seeing nine unidentified flying objects in the sky, UFO sightings have become a staple of science fiction plots, government cover-up theories, scientific inquiry, and popular culture. Eight days after Arnold's sighting, 'flying saucers' captured national attention with the alleged crash of an extraterrestrial spacecraft in Roswell, New Mexico, a town that has since built a tourism industry on its claim to fame as a UFO hotspot.

The Roswell incident prompted U.S. government probes, treasure hunters specializing in crash debris, and nearly 30 years later reports that alien corpses had been recovered at the scene of the 1947 crash. A 1994 Air Force report claimed that the original spaceship debris was, in fact, the unrecovered remnants of high altitude scientific balloon launched June 4, 1947 in Alamagordo as part of a government research project code named MOGUL. And the "alien bodies" observed in the desert? The Air Force report establishes that these were probably anthropomorphic test dummies carried in the high altitude balloons. Still, belief in the crash remained so intense that in 1997, the Air Force issued an additional report titled "The Roswell Report: Case Closed."

To read more about UFOs, go to http://www.pbs.org/wgbh/nova/aliens/

Life In The Universe Could Be Just About Everywhere

by Dan Whipple for SpaceDaily
Denver CO (UPI) May 06, 2004

The chemistry that underlies life on Earth is abundant throughout the universe -- in comets, in the interstellar medium, in the atmospheres of planets, in the outer solar system bodies and in living organisms, an astrophysicist told United Press International. "If these are made everywhere, perhaps life is everywhere," said Emma Bakes, a principal investigator with NASA's Ames Research Center in California and with the SETI Institute. SETI stands for the Search for Extra-Terrestrial Intelligence. "You have the chemical foundation spread throughout the entire galaxy," she said. "We're not special. I would bet -- if I had a million dollars -- I would bet that life is widespread across the universe." Bakes spoke on the topic at a meeting of the American Physical Society. Life's basic building blocks comprise a group of chemicals known as nitrogenated aromatics. They cover a large variety of different compounds and are defined chemically as a carbon skeleton in a ring -- a square, pentagon, hexagon and so on -- with alternating double and single bonds. They are called aromatics because in various combinations they smell of distinctive things, such as bitter almonds and bananas. With various additions, this alternating, bonded carbon ring makes up pyrroles, purines and pyrimidines, among many other chemicals. "They form the very foundations of all life on Earth," Bakes said. For instance, half of RNA and DNA molecules consists of purines, and the other half pyrimidines. They also make up oxygen-producing photopigments in plants, such as chlorophyll, oxygen-storing pigments in animals and enzymes that produce energy.

"The million-dollar question is, 'How do we get from them to us?'" Bakes asked. "It is very tantalizing to think that we can form the basic building blocks of our own genetic code between the stars." Bakes and other astrophysicists study the composition of the universe by analyzing spectra -- the unique signatures of light either emitted directly by stars or reflected by non-luminous objects, such as planets, moons, asteroids, comets, dust and gas. Using sensitive instruments called spectrometers, scientists can detect elements and compounds at great distances.

Based on such observations, Bakes said nitrogenated aromatics exist throughout the Milky Way galaxy. They can be found in protoplanetary disks around stars, in bodies in the Kuiper Belt -- the loose agglomeration of rocks and planetoids running between the orbits of Neptune and Pluto and beyond -- on comets and in interstellar space. Nitrogenated aromatics can be formed in a variety of environments. For instance, on comets, they can form in the ice and dust-grain surfaces that are a combination of methane, ammonia, hydrogen and water. In planetary atmospheres, ultraviolet radiation provides the energy for the chemical reactions needed to combine methane and nitrogen into nitrogenated aromatics.

"When we get the interstellar medium collapsing down, it forms a protoplanetary disk around the star," Bakes explained. "We get a lot of interesting chemistry." She said one hypothesis currently being researched is that comet impacts on Earth could have brought water and life-forming chemicals to the planet. Bakes said this is possible, but added these are fragile molecules. They absorb UV radiation, but when an impact is involved, she added, "you don't know how they are going to react." Currently, Bakes is studying Titan, Saturn's largest moon. "Titan is similar to what the early Earth was like," she said, "with an excess of hydrogen and methane and very little oxygen. If we analyze the chemistry of the Titan haze, we can find parallels to what might have happened here on Earth."

"It is well established and becoming more and more clear that the basic organic molecules which seem to have led to the origin of life on Earth -- as best we can reconstruct it -- do seem to be widely distributed in the galaxy," David Grinspoon, principal scientist in the department of space studies at the Southwest Research Institute in Boulder, Colo., told UPI. "Carbon behaves as if it wants to get together to form complex molecules," said Grinspoon, author of "Lonely Planets," about the possibilities for life elsewhere. "There's no question that this stuff is widely available in our galaxy and presumably in the rest of the universe. If all life needs to get going is these starting materials and a watery place, it's probably common."

The Search for Life in the Universe

By Neil deGrasse Tyson Department of Astrophysics & Hayden Planetarium, American Museum of Natural History

If the person on next to me on a long airplane flight ever finds out that I am an astrophysicist, nine times out of ten they ask, with wide eyes, about life in the universe. And only later do they ask me about the big bang and black holes. I know of no other discipline that triggers such a consistent and reliable reaction in public sentiment. This phenomenon is not limited to Americans. The time-honored question: "What is our place in the universe" might just be genetically encoded in our species. All known cultures across all of time have attempted to answer that question. Today we ask the same question, but with fewer words: "Are we alone?"

Ordinarily, there is no riskier step that a scientist (or anyone) can take than to make sweeping generalizations from just one example. At the moment, life on Earth is the only known life in the universe, but there are compelling arguments to suggest we are not alone. Indeed, most astrophysicists accept a high probability of there being life elsewhere in the universe, if not on other planets or on moons within our own solar system. The numbers are, well, astronomical: If the count of planets in our solar system is not unusual, then there are more planets in the universe than the sum of all sounds and words ever uttered by every human who has ever lived. To declare that Earth must be the only planet in the cosmos with life would be inexcusably egocentric of us.

Many generations of thinkers, both religious and scientific, have been led astray by anthropic assumptions, while others were simply led astray by ignorance. In the absence of dogma and data, history tells us that its prudent to be guided by the notion that we are not special, which is generally known as the

Copernican principle, named for the Polish astronomer Nicholas Copernicus who, in the mid 1500s, put the Sun back in the middle of our solar system where it belongs. In spite of a third century BC account of a sun-centered universe proposed by the Greek philosopher Aristarchus, the Earth-centered universe was by far the most popular view for most of the last 2000 years. Codified by the teachings of Aristotle and Ptolemy, and by the preachings of the Roman Catholic Church, people generally accepted Earth as the center of all motion. It was self-evident: the universe not only looked that way, but God surely made it so. The sixteenth century Italian monk Giordano Bruno suggested publicly that an infinite universe was filled with planets that harbor life. For these thoughts he was burned upside down and naked at the stake. Fortunately, today we live in somewhat more tolerant times.

While there is no guarantee that the Copernican principle will guide us correctly for all scientific discoveries to come, it has humbled our egos with the realization that not only is Earth not in the center of the solar system, but the solar system is not in the center of the Milky Way galaxy, and the Milky Way galaxy is not in the center of the universe. And in case you are one of those people who thinks that the edge may be a special place, then we are not at the edge of anything either.

A wise contemporary posture would be to assume that life on Earth is not immune to the Copernican principle. If so, then how can the appearance or the chemistry of life on Earth provide clues to what life might be like elsewhere in the universe? I do not know whether biologists walk around every day awestruck by the diversity of life. I certainly do. On this single planet called Earth, there co-exist (among countless other life forms), algae, beetles, sponges, jellyfish, snakes, condors, and giant sequoias. Imagine these seven living organisms lined up next to each other in size-place. If you didnt know better, you would be hard-pressed to believe that they all came from the same universe, much less the same planet. Try describing a snake to somebody who has never seen one: "You gotta believe me. There is this animal on Earth that 1) can stalk its prey with infrared detectors, 2) swallows whole live animals up to five times bigger than its head, 3) has no arms or legs or any other appendage, yet 4) can slide along level ground at a speed of two feet per second!"

Given the diversity of life on Earth, one might expect a diversity of life exhibited among Hollywood aliens. But I am consistently amazed by the film industrys lack of creativity. With a few notable exceptions such as life forms in The Blob (1958) and in 2001: A Space Odyssey (1968), Hollywood aliens look remarkably humanoid. No matter how ugly (or cute) they are, nearly all of them have two eyes, a nose, a mouth, two ears, a head, a neck, shoulders, arms, hands, fingers, a torso, two legs, two feet -- and they can walk. From an anatomical view, these creatures are practically indistinguishable from humans, yet they are supposed to have come from another planet. If anything is certain, it is that life elsewhere in the universe, intelligent or otherwise, will look at least as exotic as some of Earths own life forms.

The chemical composition of Earth-based life is primarily derived from a select few ingredients. The elements hydrogen, oxygen, and carbon account for over 95% of the atoms in the human body and in all known life. Of the three, the chemical structure of the carbon atom allows it to bond readily and strongly with itself and with many other elements in many different ways, which is how we came to be carbon-based life, and which is why the study of molecules that contain carbon is generally known as "organic" chemistry. The study of life elsewhere in the universe is known as exobiology, which is one of the few disciplines that, at the moment, attempts to function in the complete absence of first-hand data.

Is life chemically special? The Copernican principle suggests that it probably isn’t. Aliens need not look like us to resemble us in more fundamental ways. Consider that the four most common elements in the universe are hydrogen, helium, carbon, and oxygen. Helium is inert. So the three most abundant, chemically active ingredients in the cosmos are also the top three ingredients in life on Earth. For this reason, you can bet that if life is found on another planet, it will be made of a similar mix of elements. Conversely, if life on Earth were composed primarily of, for example, molybdenum, bismuth, and plutonium, then we would have excellent reason to suspect that we were something special in the universe.

Appealing once again to the Copernican principle, we can assume that the size of an alien organism is not likely to be ridiculously large compared with life as we know it. There are cogent structural reasons why you would not expect to find a life the size of the Empire State Building strutting around a planet. But if we ignore these engineering limitations of biological matter we approach another, more fundamental limit. If we assume that an alien has control of its own appendages, or more generally, if we assume the organism functions coherently as a system, then its size would ultimately be constrained by its ability to send signals within itself at the speed of light -- the fastest allowable speed in the universe. For an admittedly extreme example, if an organism were as big as the entire solar system (about 10 light-hours across), and if it wanted to scratch its head, then this simple act would take no less than 10 hours to accomplish. Sub-sloth-like behavior such as this would be evolutionarily self-limiting because the time since the beginning of the universe may be insufficient for the creature to have evolved from smaller forms of life over many generations.

Life's Building Blocks 'Abundant in Space'

By Bjorn Carey posted: 18 October 2005, www.space.com ,
http://www.space.com/scienceastronomy/051018_science_tuesday.html

The idea that comets and meteorites seeded an early Earth with the tools to make life has gained momentum from recent observations of some of these building blocks floating throughout the cosmos. Scientists scanning a galaxy 12 million light-years away with NASA's Spitzer Space Telescope detected copious amounts of nitrogen containing polycyclic aromatic hydrocarbons (PANHs), molecules critical to all known forms of life.

PANHs carry information for DNA and RNA and are an important component of hemoglobin, the molecule that transports oxygen through the body. They also make chlorophyll, the main molecule responsible for photosynthesis in plants, and – perhaps most importantly – they're the main ingredient in caffeine and chocolate. "There once was a time that the assumption was that the origin of life, everything from building simple compounds up to complex life, had to happen here on Earth," said study leader Doug Hudgins of Ames Research Center. "We've discovered that some very biologically interesting molecules can be formed outside our earthly environment and delivered here."

While organic compounds have been discovered in meteorites that have landed on Earth, this is the first direct evidence for the presence of complex, important biogenic compounds in space. So far evidence suggests that PANHs are formed in the winds of dying stars and spread all over interstellar space. "This stuff contains the building blocks of life, and now we can say they're abundant in space," Hudgins said. "And wherever there's a planet out there, we know that these things are going to be raining down on it. It did here and it does elsewhere." Using the Spitzer Space Telescope, Hudgins and his colleagues detected the familiar chemical signature of regular polycyclic aromatic hydrocarbons (PAHs) in the spiral galaxy M81, as well as a similar, but unknown signature.

"There were a few anomalies in the spectrum that we couldn't explain," Hudgins told *SPACE.com*. The researchers compared their readings to the infrared signatures of similar molecules, finally settling on nitrogen containing PANHs because their data showed there was nitrogen in the regions they were investigating.

"When we did that, we found that by putting a little nitrogen in these molecules explained the troubling molecules," Hudgins said. "This discovery takes this reservoir of molecules that we didn't think were interesting and transforms all this stuff into something of biologic interest." PAHs are flat, chicken-wire shaped molecules made up of carbon and hydrogen, interesting to scientists because life on Earth is carbon-based. However, PAHs are not used in human biochemistry. In fact, they're better known as cancer-causing carcinogens and environmental pollutants. But swap a carbon atom with a nitrogen and a PAH becomes a PANH, a class of molecules critical to humans. Without nitrogen, it would be impossible to build amino acids, proteins, DNA, RNA, hemoglobin, and many other important molecules. Here on Earth, Nitrogen makes up 78 percent of the atmosphere and is a key member of CHNOPS – carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur – the group of ingredients most important for making life and staples of organic chemistry. It's also the main component of ammonia, which is used in fertilizers and explosives on Earth, but has also been detected in Jupiter's atmosphere and possibly in Titan's icy lakes.

PANHs aren't the first of life's building blocks to be discovered in space – amino acids, the nuts and bolts of proteins, have also been found in the tails of comets. Meteorites that have landed in Australia and Antarctica also contain amino acids and PANHs. "This tells us that these things that we see out in space can survive interstellar space and successfully be delivered to the surface of a planet," Hudgins said. Some scientists even think that a Martian meteorite found in Antarctica shows signs of extraterrestrial bacteria and that sugar-loaded asteroids may have fed early life on our planet. While PANHs are abundant in interstellar space, Hudgins says this doesn't prove that terrestrial life has extra-terrestrial origins. "This isn't proof that they were used, but a likely suggestion," Hudgins said. "They were present in abundance at the dawn of time and could have been useful in creating the first life form." These findings are detailed in the October 10 2005 issue of the *Astrophysical Journal*.

Defining Life

By Leslie Mullen, www.space.com

What is life, exactly? This is a question that keeps biologists up at night. The science of biology is the study of life, yet scientists can't agree on an absolute definition. Are the individual cells of your body, with all their complex machinery, "alive?" What about a computer program that learns and evolves? Can a wild fire - which feeds, grows, and reproduces - be considered a living entity? Trying to define life is not just a philosophical exercise. We need to understand what separates living creatures from non-living matter before we can claim to find life elsewhere in the Universe. In 1944, the physicist Erwin Shrodinger defined living matter as that which "avoids the decay into equilibrium." This definition refers to the Second Law of Thermodynamics, which says that entropy always increases. Entropy is often referred to as chaos or disorder, but really it is the spreading out of energy towards a state of uniformity. This law can be seen in a cold glass of water that slowly grows warmer until it is the same temperature as the surrounding air. Because of this trend toward equilibrium, the Universe eventually will have a complete lack of structure, consisting of evenly spread atoms of equal warmth.

But living things, said Shrodinger, are able to postpone this trend. Consider: while you are alive your body maintains its structure, but once you die your body begins to break down through bacterial action and chemical processes. Eventually the atoms of your body are evenly spread out, recycled by the Earth. To die is to submit your body to the entropy of the Universe. Living things resist entropy by taking in nutrients. This biochemical process of taking in energy for activities and expelling waste byproducts is known as a "metabolism." If metabolism is a sign of life, scientists can look for the waste byproducts of a metabolism when searching for life on other worlds. At least, that was the idea behind the Viking Lander's Labeled Release Experiment, conducted on Mars in 1976. This experiment tested for metabolic clues to life by adding radioactively labeled liquid nutrients to a sample of Martian soil. If these nutrients were consumed by life forms, any gases released as waste byproducts would also be radioactively labeled. After the nutrient was injected, there was a rapid increase in carbon dioxide (CO_2) gas. Because this gas had the radioactive label, scientists at first concluded that organisms in the Martian soil were eating the nutrient and releasing the CO_2 as a waste byproduct. However, the Martian soil turned out to have a unique soil chemistry that could produce a metabolic-like reaction. Although the test remains inconclusive, most scientists believe that non-living, chemical processes in the Martian soil caused the "metabolic" reaction. The Viking experiments showed that while metabolism may be a quality of life, it is not a narrow enough guideline to search for life elsewhere.

Another quality of all life on Earth is a dependence on water. Since water plays such a crucial role in all known life forms, many scientists believe that water-use will be a quality universal to all life. But Benton Clark, an astrobiologist with the University of Colorado and Lockheed Martin, says that water is really a side issue. "Water doesn't define life, it is just an aspect of our environment," says Clark. Life on Earth evolved with water, and so today life on Earth is dependent on that resource. But we cannot say that without water, life is impossible. Steven Benner, an astrobiologist with the University of Florida, agrees that water is not necessarily a universal quality of life. "We can conceive of chemistries that might occur in sulfuric acid as a solvent - as on Venus - or in methane-ammonia mixtures - as on Jupiter," says Benner. "Discovering these would have a profound impact on our view of life, however, as well as the way that NASA looks for it." A recent definition of life created by Gerald Joyce of the Scripps Research Institute doesn't mention either metabolism or water. This definition says that life is "a self-sustaining system capable of Darwinian evolution." But Clark says most life forms technically are not self-sustaining. Animals feed on plants or other animals, plants need microorganisms at their roots to take up nutrients, and bacteria often live inside other organisms, relying on the internal environment of their host. He says the only truly self-sustaining organisms are chemolithotrophs and photolithotrophs, and they are relatively rare.

Clark says that Darwinian evolution is another problematic criteria. How could you tell if something has undergone Darwinian evolution? The time scales involved are enormous - scientists would need a complete understanding of an organism's fossil history before being able to declare that the object is, indeed, alive. According to Clark, living organisms exhibit at least 102 observable qualities. Adding all these qualities together into a single - if exceedingly long - definition still does not capture the essence of life. But Clark has picked out three qualities from this list that he considers universal, creating a new definition of life. This definition says that "life reproduces, and life uses energy. These functions follow a set of instructions embedded within the organism."

The instructions are the DNA and RNA "letters" that make up the genetic code in all organisms on Earth. A wild fire, one might say, reproduces and uses energy. So do crystals and various chemical reactions. In fact, Benner says that, "every spontaneous chemical process must expend free energy, living or not." But Clark says none of these phenomena are "alive" because none of them have the embedded instructions of a genetic code. We know there are no instructions, because there has not been any mutation over the years. They follow the rules of physics rather than embedded instructions, and so they behave the same every time. Mutation, says Clark, is the key to understanding whether or not something has embedded instructions. Not all living things are capable of reproduction, however. Mules are born sterile. Most honeybees do not reproduce: only the Queen bee has that honor. Many human beings live their entire lives without producing offspring, and no one would argue that such people were not therefore alive. But Clark says that reproduction and energy-use need not both occur for life to exist. He divides life into two categories: "organisms" and "Lifeforms." Organisms channel energy according to embedded instructions, and this energy allows the organism to perform certain activities. A Lifeform, says Clark, is a broader category that encompasses organisms and makes reproduction possible. "What I am proposing is that the individual physical entities should be called 'organisms,' but it sometimes takes a collection of organisms, the 'Lifeform,' to achieve reproduction,".

There have been many definitions of life created over the years, but there has yet to be a single definition accepted by all. Every definition has had to face down challenges to its validity. According to Carol Cleland of the University of Colorado, this is because definitions are concerned only with language and concepts; they can't expand our understanding of the world. We can only define things we already understand.Cleland says that scientists in the seventeenth century had the same problem trying to define water. There are many descriptions of water - it's wet, thirst-quenching, it freezes and turns into vapor - but other substances also have these qualities. Once scientists discovered molecular chemistry, they could define water to everyone's satisfaction as one oxygen atom coupled with two hydrogen atoms (H2O). Perhaps we need a similar revolution in scientific thought in order to define life. "Current attempts to answer the question, 'What is life?' by defining life in terms of features like metabolism or reproduction - features that we ordinarily use to recognize samples of terrestrial life - are unlikely to succeed," says Cleland. "What we need to answer the question, 'What is life?' is a general theory of living systems." Could we use Clark's definition to find life on other worlds? The Viking Lander already looked for energy-use in the form of a metabolism, and the results were inconclusive. To search for this criterion as a means for finding life, we would need to consider other ways life could use energy. The problem with searching for life forms with embedded instructions, says Clark, is that the criteria may be too specific. The only instructions we know of are DNA and RNA - there may be other genetic systems possible in the Universe that do not resemble the system found here on Earth.