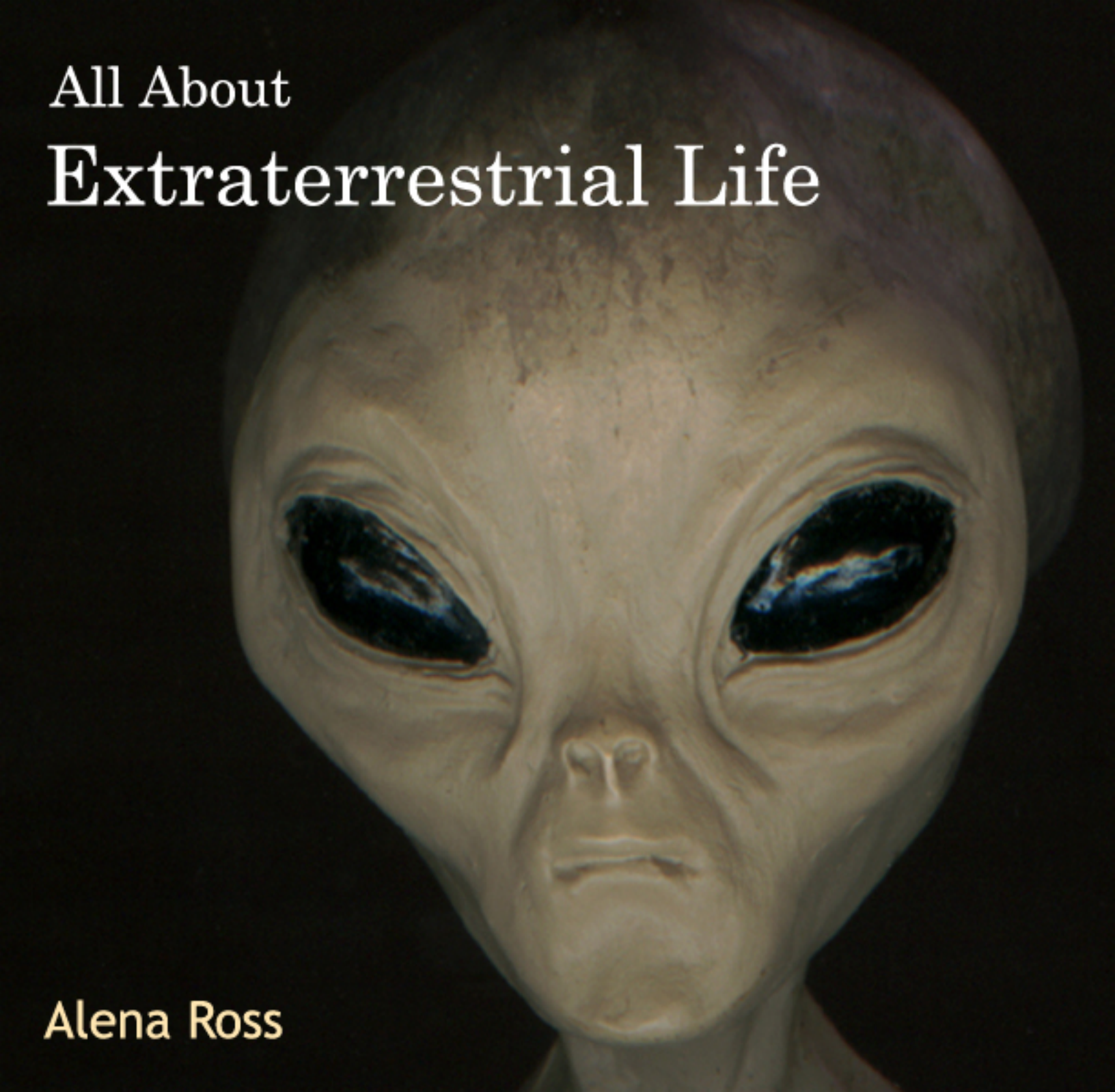
All About
Extraterrestrial Life
Alena Ross

First Edition, 2012

ISBN 978-81-323-3702-7

Published by:
University Publications
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

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Chapter- 1

Extraterrestrial Life

A 1967 Soviet Union 16 kopeks postage stamp, depicting a satellite from an imagined extraterrestrial civilization.

Extraterrestrial life (from the Latin words: *extra* ("beyond", or "not of") and *terrestris* ("of or belonging to Earth")) is defined as life that does not originate from Earth. Possible forms of extraterrestrial life range from simple bacteria-like organisms to sapient beings far more advanced than humans. It is unknown whether any such forms of life exist or ever existed.

The development and testing of theories about extraterrestrial life is known as exobiology, xenobiology or astrobiology; the term astrobiology however also covers the study of life on Earth, viewed in its astronomical context.

Various claims have been made for evidence of extraterrestrial life, such as those listed in a 2006 *New Scientist* article, which the magazine describes as "hints" rather than proof. A less direct argument for the existence of extraterrestrial life relies on the vast size of the observable Universe. According to this argument, endorsed by scientists such as Carl Sagan and Stephen Hawking, it would be improbable for life *not* to exist somewhere other than Earth and its spacecrafts.

One possibility is that life has emerged independently at many places throughout the Universe. Another possibility is panspermia or exogenesis, in which life would have spread between habitable planets. These two hypotheses are not necessarily mutually exclusive.

Suggested locations at which life might have developed, or which might continue to host life today, include the planets Venus and Mars; moons of Jupiter, such as Europa ; moons of Saturn, such as Titan and Enceladus; and extrasolar planets, such as Gliese 581 c, g and d, recently discovered to be near Earth mass and apparently located in their star's habitable zone, with the potential to have liquid water.

Beliefs that some unidentified flying objects are of extraterrestrial origin, along with claims of alien abduction, are considered spurious by most scientists. Most UFO sightings are explained either as sightings of Earth-based aircraft or known astronomical objects, or as hoaxes.

Possible basis of extraterrestrial life

Several theories have been proposed about the possible basis of alien life from a biochemical, evolutionary or morphological viewpoint.

Alien life, such as bacteria, has been theorized by scientists such as Carl Sagan to exist in the Solar System and quite possibly throughout the Universe. No samples have been found, although there is some controversy about possible traces of life in Martian material, of which the most famous are on the Allan Hills 84001 meteorite.

Biochemistry

All life on Earth requires carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur (CHNOPS) as well as numerous other elements in smaller amounts; it also requires water as the solvent in which biochemical reactions take place. Sufficient quantities of carbon and the other major life-forming elements, along with water, may enable the formation of living organisms on other planets with a chemical make-up and average temperature similar to that of Earth. Because Earth and other planets are made up of "stardust", i.e. relatively abundant chemical elements formed from stars which have ended their lives as supernovae, it is very probable that other planets may have been formed by elements of a similar composition to the Earth's. The combination of carbon, hydrogen and oxygen in the chemical form of carbohydrates (e.g. sugar) can be a source of chemical energy on which life depends, and can also provide structural elements for life (such as ribose, in the molecules DNA and RNA, and cellulose in plants). Plants derive energy through the conversion of light energy into chemical energy via photosynthesis. Life, as currently recognized, requires carbon in both reduced (methane derivatives) and partially-oxidized (carbon oxides) states. It also appears to require nitrogen as a reduced ammonia derivative in all proteins, sulfur as a derivative of hydrogen sulfide in some necessary proteins, and phosphorus oxidized to phosphates in genetic material and in energy transfer. Adequate water as a solvent supplies adequate oxygen as constituents of biochemical substances.

Pure water is useful because it has a neutral pH due to its continued dissociation between hydroxide and hydronium ions. As a result, it can dissolve both positive metallic ions and negative non-metallic ions with equal ability. Furthermore, the fact that organic molecules can be either hydrophobic (repelled by water) or hydrophilic (soluble in water) creates the ability of organic compounds to orient themselves to form water-enclosing membranes. The fact that solid water (ice) is less dense than liquid water (within specific temperature ranges) also means that ice floats, thereby preventing Earth's oceans from slowly freezing. Without this quality, the oceans could have frozen solid during the Snowball Earth episodes. Additionally, the hydrogen bonds between water molecules give it an ability to store energy with evaporation, which upon condensation is released. This helps to moderate the climate, cooling the tropics and warming the poles, helping to maintain the thermodynamic stability needed for life.

Carbon is fundamental to terrestrial life for its immense flexibility in creating covalent chemical bonds with a variety of non-metallic elements, principally nitrogen, oxygen and hydrogen. Carbon dioxide and water together enable the storage of solar energy in sugars, such as glucose. The oxidation of glucose releases biochemical energy needed to fuel all other biochemical reactions.

The ability to form organic acids (–COOH) and amine bases ($–NH_2$) gives rise to the possibility of neutralization dehydrating reactions to build long polymer peptides and catalytic proteins from monomer amino acids, and with phosphates to build not only DNA (the information-storing molecule of inheritance), but also ATP (the principal energy "currency" of cellular life).

Due to their relative abundance and usefulness in sustaining life, many have hypothesized that life forms elsewhere in the universe would also utilize these basic materials. However, other elements and solvents could also provide a basis for life. Silicon is most often deemed to be the probable alternative to carbon. Silicon life forms are proposed to have a crystalline morphology, and are theorized to be able to exist in high temperatures, such as on planets which are very close to their star. Life forms based in ammonia (rather than water) have also been suggested, though this solution appears less optimal than water.

When looked at from a chemical perspective, life is fundamentally a self-replicating reaction, but one which could arise under a great many conditions and with various possible ingredients, though carbon-oxygen within the liquid temperature range of water seems most conducive. Suggestions have even been made that self-replicating reactions of some sort could occur within the plasma of a star, though it would be highly unconventional.

Several pre-conceived ideas about the characteristics of life outside of Earth have been questioned. For example, NASA scientists believe that the color of photosynthesizing pigments on extrasolar planets might not be green.

Evolution and morphology

In addition to the biochemical basis of extraterrestrial life, many have also considered evolution and morphology. Science fiction has often depicted extraterrestrial life with humanoid and/or reptilian forms. Aliens have often been depicted as having light green or grey skin, with a large head, as well as four limbs—i.e. fundamentally humanoid. Other subjects, such as felines and insects, etc., have also occurred in fictional representations of aliens.

A division has been suggested between universal and parochial (narrowly restricted) characteristics. Universals are features which are thought to have evolved independently more than once on Earth (and thus, presumably, are not too difficult to develop) and are so intrinsically useful that species will inevitably tend towards them. These include flight, sight, photosynthesis and limbs, all of which are thought to have evolved several times here on Earth. There is a huge variety of eyes, for example, and many of these have radically different working schematics and different visual foci: the visual spectrum, infrared, polarity and echolocation. Parochials, however, are essentially arbitrary evolutionary forms. These often have little inherent utility (or at least have a function which can be equally served by dissimilar morphology) and probably will not be replicated. Intelligent aliens could communicate through gestures, as deaf humans do, or by sounds created from structures unrelated to breathing, which happens on Earth when, for instance, cicadas vibrate their wings, or crickets rub their legs.

Attempting to define parochial features challenges many taken-for-granted notions about morphological necessity. Skeletons, which are essential to large terrestrial organisms according to the experts of the field of gravitational biology, are almost assured to be

replicated elsewhere in one form or another. Many also conjecture as to some type of egg-laying amongst extraterrestrial creatures, but mammalian mammary glands might be a singular case.

The assumption of radical diversity amongst putative extraterrestrials is by no means settled. While many exobiologists do stress that the enormously heterogeneous nature of life on Earth foregrounds an even greater variety in outer space, others point out that convergent evolution may dictate substantial similarities between Earth and extraterrestrial life. These two schools of thought are called "divergionism" and "convergionism" respectively.

Beliefs in extraterrestrial life

Ancient and medieval ideas

In antiquity, it was common to assume a cosmos consisting of "many worlds" inhabited by intelligent, non-human life-forms, but these "worlds" were mythological and not informed by the heliocentric understanding of the solar system, or the understanding of the Sun as one among countless stars. An example would be the fourteen loka of Hindu cosmology, or the Nine Worlds of Old Norse mythology, etc. The Sun and the Moon often appear as inhabited worlds in such contexts, or as vehicles (chariots or boats, etc.) driven by gods. The Japanese folk tale of *The Tale of the Bamboo Cutter* (10th century) is an example of a princess of the Moon people visiting Earth.

Such conceptions of a universe consisting of "many worlds" are also found in classical Greek philosophy, and later in Christian and Jewish theology. The first important thinkers to argue systematically for a Universe full of other planets and, therefore, possible extraterrestrial life were the ancient Greek writer Thales and his student Anaximander in the 7th and 6th centuries B.C. The atomists of Greece like Epicurus took up the idea, arguing that an infinite universe ought to have an infinity of populated worlds. Ancient Greek cosmology worked against the idea of extraterrestrial life in one critical respect, however: the geocentric Universe. Championed by Aristotle and codified by Ptolemy, it favored the Earth and Earth-life (Aristotle denied that there could be a plurality of worlds) and seemingly rendered extraterrestrial life philosophically untenable. Lucian of Samosata, in his novels, described inhabitants of the Moon and other celestial bodies as humanoids, but significantly different from humans.

The Jewish Talmud states that there are at least 18,000 other worlds, but provides little elaboration on the nature of those worlds, or on whether they are physical or spiritual. Based on this, however, the 18th century exposition "Sefer HaB'rit" posits that extraterrestrial creatures exist, and that some may well possess intelligence. It adds that humans should not expect creatures from another world to resemble earthly life any more than sea creatures resemble land animals.

Hindu beliefs of endlessly repeated cycles of life have led to descriptions of multiple worlds in existence and their mutual contacts (Sanskrit word *sampark* means "contact" as

in Mahasamparka "the great contact"). According to Hindu scriptures, there are innumerable universes to facilitate the fulfillment of the separated desires of innumerable living entities. However, the purpose of such creations is to bring back the deluded souls to correct understanding about the purpose of life. Aside from the innumerable universes which are material, there is also the unlimited spiritual world, where the purified living entities live with perfect conception about life and ultimate reality. The spiritually aspiring saints and devotees, as well as thoughtful men of the material world, have been getting guidance and help from these purified living entities of the spiritual world from time immemorial. However, the relevance of such descriptions has to be evaluated in the context of a correct understanding of geography and science at those times.

Within Islam, the statement of the Qur'an "All praise belongs to God, Lord of all the worlds" indicates multiple universal bodies, and maybe even multiple universes, which may indicate extraterrestrial and even extradimensional life. Surat Al-Jinn also mentions a statement from a Jinn regarding the current status and ability of his group in the heavens.

According to Ahmadiyya Islam a more direct reference from the Quran is presented by Mirza Tahir Ahmad as a proof that life on other planets may exist according to the Quran. In his book, *Revelation, Rationality, Knowledge & Truth*, he quotes verse 42:29 "And among His Signs is the creation of the heavens and the earth, and of whatever living creatures (*da'bbah*) He has spread forth in both..."; according to this verse there is life in heavens. According to the same verse "And He has the power to gather them together (*jam-'i-him*) when He will so please"; indicates the bringing together the life on Earth and the life elsewhere in the Universe. The verse does not specify the time or the place of this meeting but rather states that this event will most certainly come to pass whenever God so desires. It should be pointed out that the Arabic term Jam-i-him used to express the gathering event can imply either a physical encounter or a contact through communication.

In Shia Islam the 6th Imam Ja'far al-Sadiq has been quoted as saying that there are living beings on other planets. He has also stated that they may be more intelligent or advanced than humans.

When Christianity spread throughout the West, the Ptolemaic system became very widely accepted, and although the Church never issued any formal pronouncement on the question of alien life, at least tacitly, the idea was aberrant. In 1277, the Bishop of Paris, Étienne Tempier, did overturn Aristotle on one point: God *could* have created more than one world (given His omnipotence). Taking a further step, and arguing that aliens actually existed, remained rare. Notably, Cardinal Nicholas of Kues speculated about aliens on the Moon and Sun.

Early modern period

Giordano Bruno, *De l'Infinito, Universo e Mondi, 1584*

There was a dramatic shift in thinking initiated by the invention of the telescope and the Copernican assault on geocentric cosmology. Once it became clear that the Earth was merely one planet amongst countless bodies in the universe, the extraterrestrial idea moved towards the scientific mainstream. The best known early-modern proponent of such ideas was the Italian philosopher Giordano Bruno, who argued in the 16th century for an infinite Universe in which every star is surrounded by its own planetary system. Bruno's thoughts about God and the Universe, of which many contradicted essential dogmas of the Catholic Faith, led to his eventual condemnation as a heretic by a tribunal of the Roman Inquisition of the Roman Catholic Church. Contemporary civil authorities enforced the penal statute of Emperor Frederick II Inconsutilem Tunicam of 12 February 1220 mandating the burning of heretics, resulting in his being among the last of heretics to be burned alive at the stake in Rome in the year 1600.

In the early 17th century, the Czech astronomer Anton Maria Schyrleus of Rheita mused that "if Jupiter has (...) inhabitants (...) they must be larger and more beautiful than the inhabitants of the Earth, in proportion to the [characteristics] of the two spheres". The Catholic Church has not made a formal ruling on the existence of extraterrestrials. However, writing in the Vatican newspaper, the astronomer, Father José Gabriel Funes, director of the Vatican Observatory near Rome, said in 2008 that intelligent beings created by God could exist in outer space.

In Baroque literature such as *The Other World: The Societies and Governments of the Moon* by Cyrano de Bergerac, extraterrestrial societies are presented as humoristic or ironic parodies of earthly society. The didactic poet Henry More took up the classical theme of the Greek Democritus in "Democritus Platonissans, or an Essay Upon the Infinity of Worlds" (1647). In "The Creation: a Philosophical Poem in Seven Books"

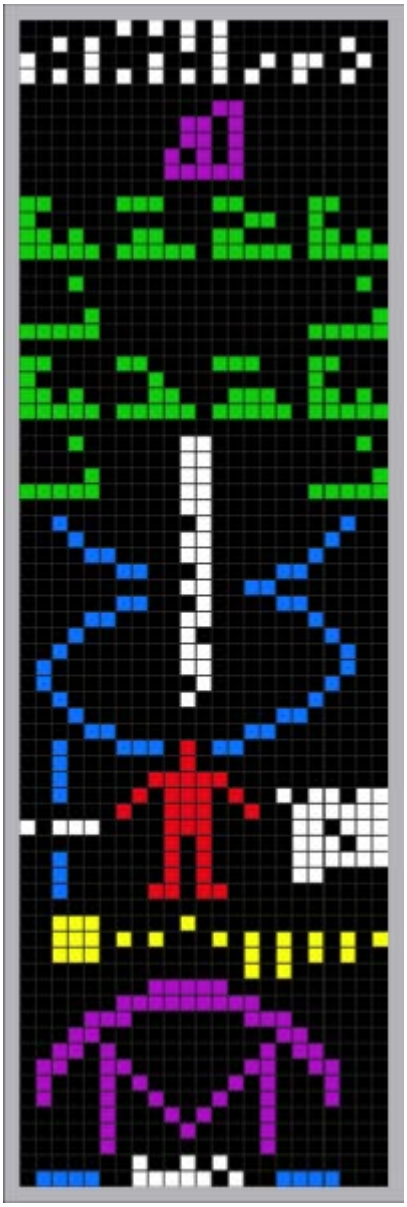
(1712), Sir Richard Blackmore observed: "We may pronounce each orb sustains a race / Of living things adapted to the place". With the new relative viewpoint that the Copernican revolution had wrought, he suggested "our world's sunne / Becomes a starre elsewhere". Fontanelle's "Conversations on the Plurality of Worlds" (translated into English in 1686) offered similar excursions on the possibility of extraterrestrial life, expanding, rather than denying, the creative sphere of a Maker.

The possibility of extraterrestrials remained a widespread speculation as scientific discovery accelerated. William Herschel, the discoverer of Uranus, was one of many 18th–19th century astronomers convinced that the Solar System, and perhaps others, would be well-populated by alien life. Other luminaries of the period who championed "cosmic pluralism" included Immanuel Kant and Benjamin Franklin. At the height of the Enlightenment, even the Sun and Moon were considered candidates for extraterrestrial inhabitants.

19th century

The science fiction genre, although not so named during the time, develops during the late 19th century. Jules Verne's *Around the Moon* (1870) features a discussion of the possibility of life on the Moon, but with the conclusion that it is barren. Stories involving extraterrestrials are found in e.g. Garrett P. Serviss's *Edison's Conquest of Mars* (1897). *The War of the Worlds* by H. G. Wells was published in 1898 and stands at the beginning of the popular idea of the "Martian invasion" of Earth prominent in 20th century pop culture.

20th century



The Arecibo message is a digital message sent to globular star cluster M13, and is a well-known symbol of human attempts to contact extraterrestrials.

A radio drama version of Wells' novel broadcast in 1938 over the CBS Radio Network led to outrage because it supposedly suggested to many listeners that an actual alien invasion by Martians was currently in progress. In the wake of this, Conspiracy theories on the presence of extraterrestrials became a widespread phenomenon in the United States during the 1940s and the beginning Space Age during the 1950s, accompanied by a surge of UFO reports. The term UFO itself was coined in 1952 in the context of the enormous popularity of the concept of "flying saucers" in the wake of the Kenneth Arnold UFO sighting in 1947. The Majestic 12 documents published in 1982 suggest that there was genuine interest in UFO conspiracy theories in the US government during the 1940s.

The trend to assume that celestial bodies were populated almost by default was tempered as actual probes visited potential alien abodes in the Solar System beginning in the second half of the 20th century, and by the 1970s belief in UFOs had become part of the fringe beliefs associated with the paranormal, New Age, Earth mysteries, Forteana etc. A number of UFO religions developed during the surge in UFO belief during th 1950s to 1970s period, and some, such as Scientology (founded 1953) and Raëlism (founded 1974) remain active into the present. The idea of "paleocontact", supposing that extraterrestrials ("ancient astronauts") have visited the Earth in the remote past and left traces in ancient cultures, appears in early 20th century fiction such as *The Call of Cthulhu* (1926), but it was given serious consideration in 1966 by astrophysicists I.S. Shklovski and Carl Sagan, and the idea came to be established as a notable aspect of the Ufology subculture in the wake of Erich von Däniken's *Chariots of the Gods?* (1968). Alien abduction claims were also widespread during the 1960s and 1970s in the United States.

On the scientific side, the possibility of extraterrestrial life on the Moon was decisively ruled out by the 1960s, and during the 1970s it became clear that most of the other bodies of the Solar System do not harbour highly developed life, although the question of primitive life on bodies in the Solar System remains an open question. Carl Sagan, Bruce Murray, and Louis Friedman founded the U.S. Planetary Society, partly as a vehicle for SETI studies in 1980, and since the 1990s, systematic search for radio signals attributable to intelligent extraterrestrial life has been ongoing.

Recent history

The failure of the SETI program to announce an intelligent radio signal after decades of effort has at least partially dimmed the prevailing optimism of the beginning of the space age. Notwithstanding, the unproven belief in extraterrestrial beings continues to be voiced in pseudoscience, conspiracy theories, and in popular folklore, notably "Area 51" and legends, but has also become a pop culture trope given less-than-serious treatment in popular entertainment with e.g. the ALF TV series (1986-1990), *The X-Files* (1993-2002), etc.

The SETI program is not the result of a continuous, dedicated search, but instead utilizes what resources and manpower it can, when it can. Furthermore, the SETI program only searches a limited range of frequencies at any one time.

In the words of SETI's Frank Drake, "All we know for sure is that the sky is not littered with powerful microwave transmitters". Drake has also noted that it is entirely possible that advanced technology results in communication being carried out in some way other than conventional radio transmission. At the same time, the data returned by space probes, and giant strides in detection methods, have allowed science to begin delineating habitability criteria on other worlds, and to confirm that at least other planets are plentiful, though aliens remain a question mark. The Wow! signal, from SETI, remains a speculative debate.

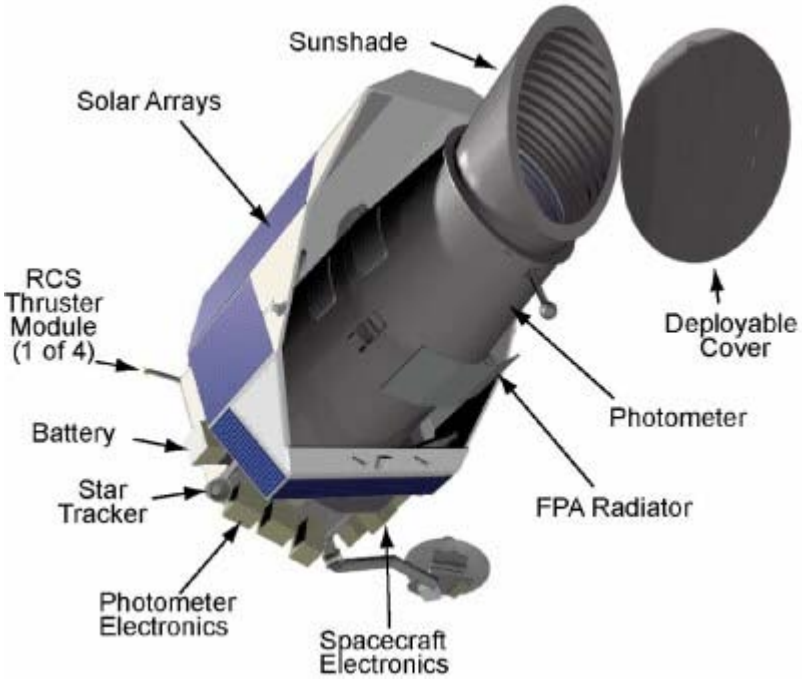
In 2000, geologist and paleontologist Peter Ward and astrobiologist Donald Brownlee published a book entitled *Rare Earth: Why Complex Life is Uncommon in the Universe*. In it, they discussed the Rare Earth hypothesis, in which they claim that Earth-like life is rare in the Universe, while microbial life is common. Ward and Brownlee are open to the idea of evolution on other planets which is not based on essential Earth-like characteristics (such as DNA and carbon).

The possible existence of primitive (microbial) life outside of Earth is much less controversial to mainstream scientists, although, at present, no direct evidence of such life has been found. Indirect evidence has been offered for the current existence of primitive life on Mars. However, the conclusions that should be drawn from such evidence remain in debate.

In September 2010, it was reported that the U.N. General Assembly had appointed Mazlan Othman as their official extraterrestrial liaison by the UK paper *The Sunday Times*. This claim was later refuted.

Theoretical physicist Stephen Hawking in 2010 warned that humans should not try to contact alien life forms. He warned that aliens might pillage Earth for resources. "If aliens visit us, the outcome would be much as when Columbus landed in America, which didn't turn out well for the Native Americans," he said. Geographer Jared Diamond has also expressed similar concerns.

Scientific search for extraterrestrial life



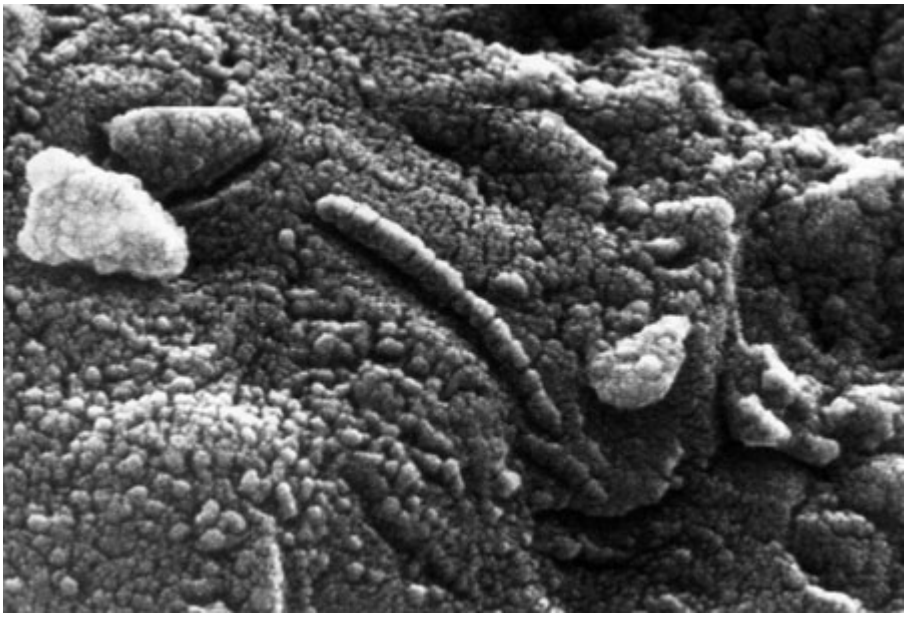
The NASA Kepler Mission for the search of extrasolar planets.

The scientific search for extraterrestrial life is being carried out both directly and indirectly.

Direct search

Scientists are directly searching for evidence of unicellular life within the Solar System, carrying out studies on the surface of Mars and examining meteors which have fallen to Earth. A mission is also proposed to Europa, one of Jupiter's moons with a possible liquid water layer under its surface, which might contain life.

There is some limited evidence that microbial life might possibly exist (or have existed) on Mars. An experiment on the Viking Mars lander reported gas emissions from heated Martian soil that some argue are consistent with the presence of microbes. However, the lack of corroborating evidence from other experiments on the Viking lander indicates that a non-biological reaction is a more likely hypothesis. Independently, in 1996, structures resembling nanobacteria were reportedly discovered in a meteorite, ALH84001, thought to be formed of rock ejected from Mars. This report is also controversial, and scientific debate continues.



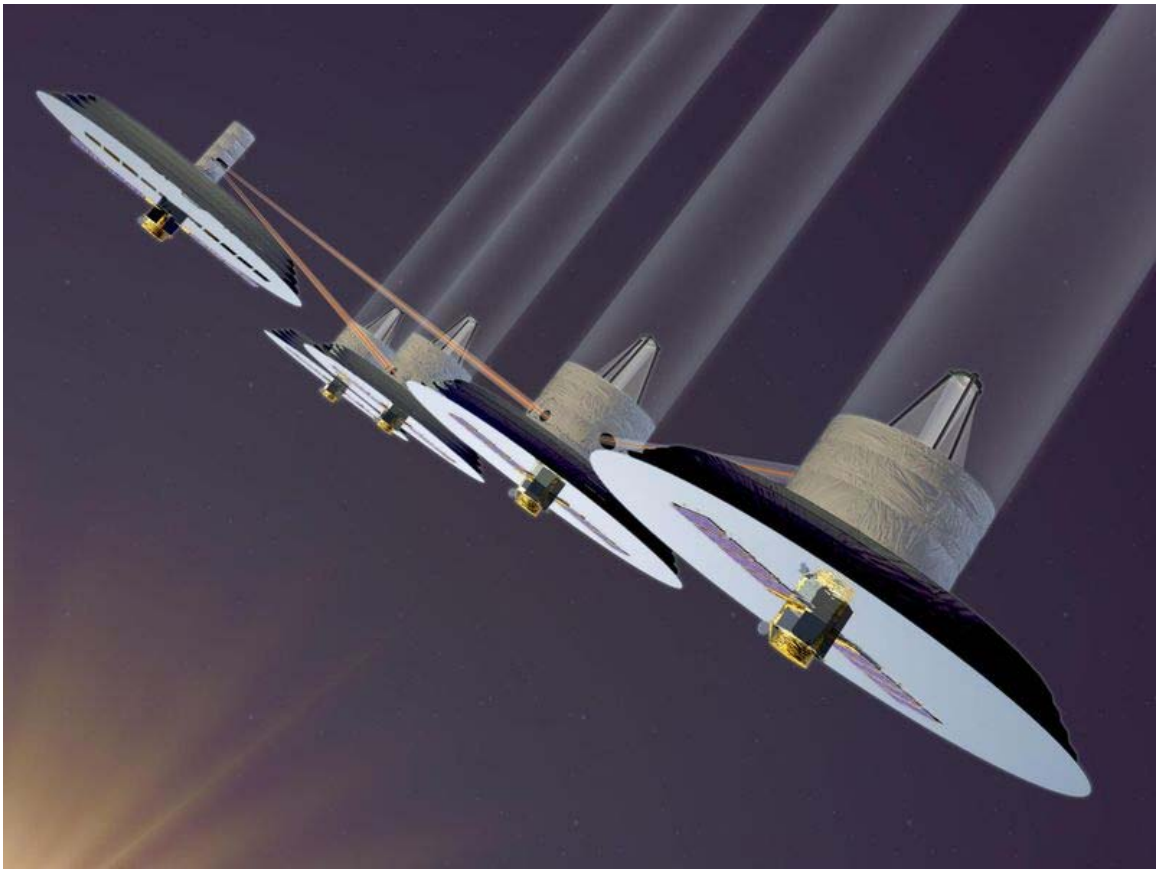
Electron micrograph of martian meteorite ALH84001 showing structures that some scientists think could be fossilized bacteria-like life forms.

In February 2005, NASA scientists reported that they had found strong evidence of present life on Mars. The two scientists, Carol Stoker and Larry Lemke of NASA's Ames Research Center, based their claims on methane signatures found in Mars' atmosphere resembling the methane production of some forms of primitive life on Earth, as well as on their own study of primitive life near the Rio Tinto river in Spain. NASA officials soon denied the scientists' claims, and Stoker herself backed off from her initial assertions.

Though such findings are still very much in debate, support among scientists for the belief in the existence of life on Mars seems to be growing. In an informal survey conducted at the conference at which the European Space Agency presented its findings, 75 percent of the scientists in attendance were reported to believe that life once existed on Mars, and 25 percent reported a belief that life currently exists there.

The Gaia hypothesis stipulates that any planet with a robust population of life will have an atmosphere in chemical disequilibrium, which is relatively easy to determine from a distance by spectroscopy. However, significant advances in the ability to find and resolve light from smaller rocky worlds near their star are necessary before such spectroscopic methods can be used to analyze extrasolar planets.

Indirect search



Terrestrial Planet Finder - A planned Infrared interferometer for finding Earth-like extrasolar planets (as of 2010, it has not received the funding from NASA which it needs—that funding is going towards the Kepler mission).

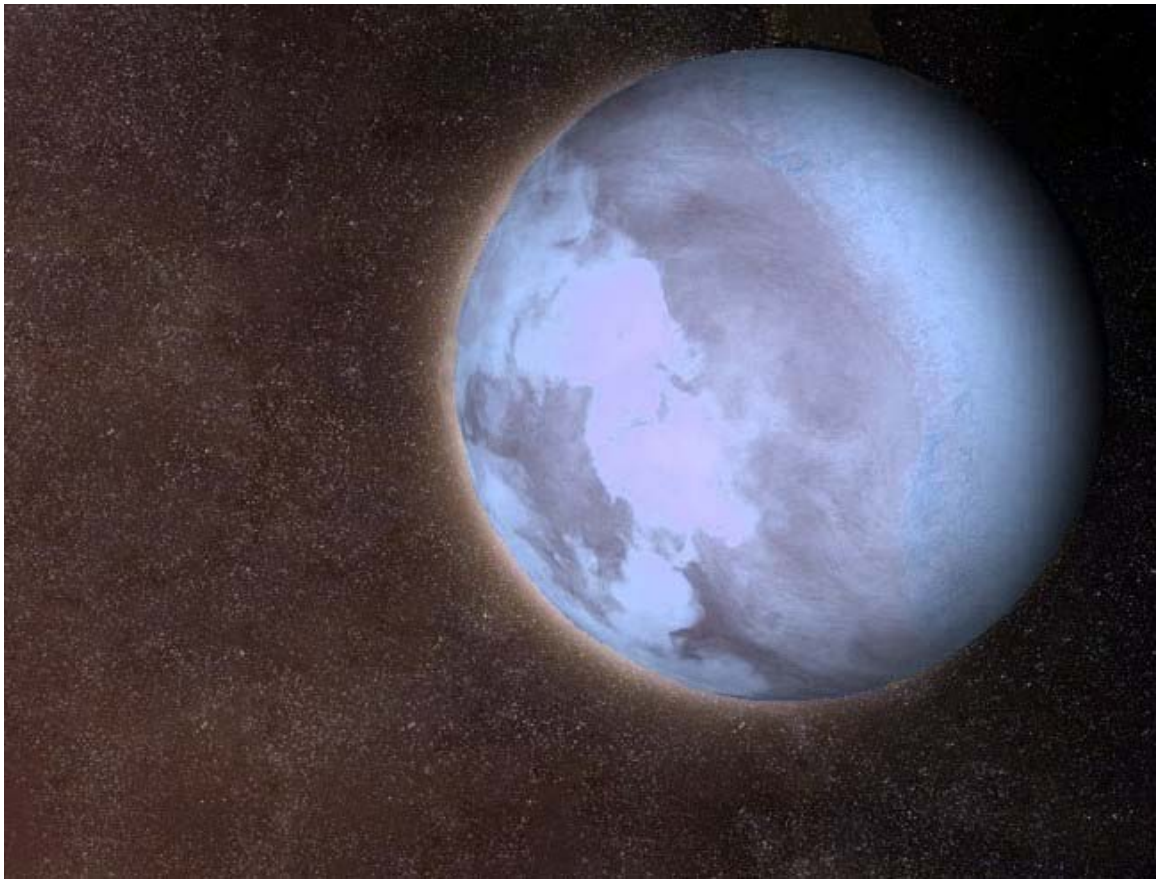
It is theorized that any technological society in space will be transmitting information. However, since there are no human systems, in general, intentionally transmitting information randomly into deep space, there is no guarantee that any other species would

do so either. Also, the length of time required for a signal to travel across the vastness of space means that any signal detected, or not detected, would come from the distant past.

Nevertheless, projects such as SETI are conducting an astronomical search for radio activity which would confirm the presence of intelligent life. A related suggestion is that aliens might broadcast pulsed and continuous laser signals in the optical, as well as infrared, spectrum; laser signals have the advantage of not "smearing" in the interstellar medium, and may prove more conducive to communication between the stars. While other communication techniques, including laser transmission and interstellar spaceflight, have been discussed seriously and may well be feasible, the measure of effectiveness is the amount of information communicated per unit cost. This results in radio transmission as the method of choice.

Extrasolar planets

Astronomers also search for extrasolar planets that they believe would be conducive to life, such as Gliese 581 c, Gliese 581 g, Gliese 581 d and OGLE-2005-BLG-390Lb, which have been found to have Earth-like qualities. Current radiodetection methods have been inadequate for such a search, since the resolution afforded by recent technology is inadequate for a detailed study of extrasolar planetary objects. Future telescopes should be able to image planets around nearby stars, which may reveal the presence of life — either directly or through spectrography which would reveal key information, such as the presence of free oxygen in a planet's atmosphere:



Artist's Impression of Gliese 581 c, the first extrasolar planet discovered within its star's habitable zone.

- Darwin was a proposed ESA mission designed to find Earth-like planets and analyze their atmosphere.
- The COROT mission, initiated by the French Space Agency, was launched in 2006, and is currently looking for extrasolar planets; it is the first of its kind.
- The Terrestrial Planet Finder was supposed to have been launched by NASA, but as of 2010, budget cuts have caused it to be delayed indefinitely.
- The Kepler Mission, largely replacing the Terrestrial Planet Finder, was launched in March 2009.

It has been argued that Alpha Centauri, the closest star system to Earth, may contain planets which could be capable of sustaining life.

On April 24, 2007, scientists at the European Southern Observatory in La Silla, Chile said they had found the first Earth-like planet. The planet, known as Gliese 581 c, orbits within the habitable zone of its star Gliese 581, a red dwarf star which is 20.5 light years (194 trillion km) from the Earth. It was initially thought that this planet could contain liquid water, but recent computer simulations of the climate on Gliese 581 c by Werner von Bloh and his team at Germany's Institute for Climate Impact Research suggest that carbon dioxide and methane in the atmosphere would create a runaway greenhouse

effect. This would warm the planet well above the boiling point of water (100 degrees Celsius/212 degrees Fahrenheit), thus dimming the hopes of finding life. As a result of greenhouse models, scientists are now turning their attention to Gliese 581 d, which lies just outside of the star's traditional habitable zone.

On May 29, 2007, the Associated Press released a report stating that scientists identified twenty-eight new extra-solar planetary bodies. One of these newly-discovered planets is said to have many similarities to Neptune.

Extrasolar planets have been discovered on a regular basis since 1992, with 520 confirmed as of January 10, 2011.

Drake equation

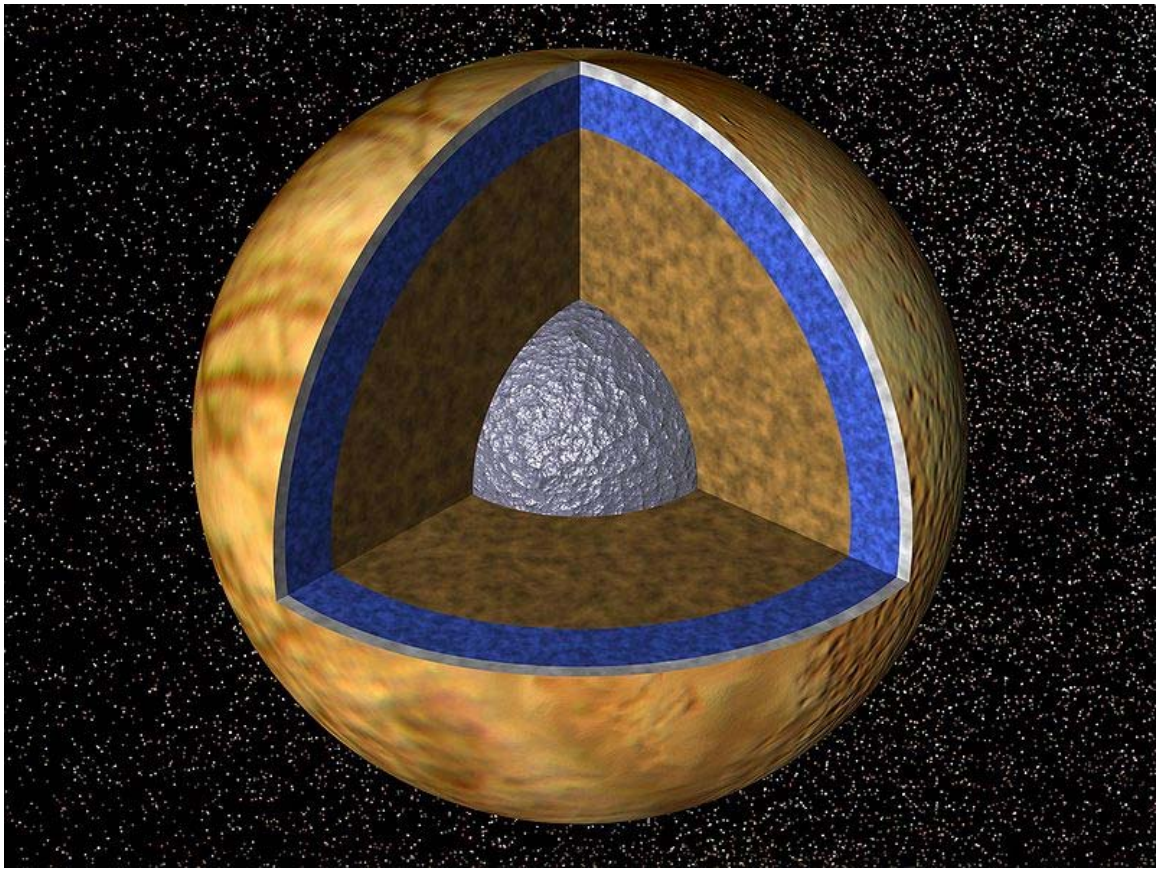
In 1961, University of California, Santa Cruz astronomer and astrophysicist Dr. Frank Drake devised the Drake equation. This controversial equation multiplied estimates of the following terms together:

- The rate of formation of suitable stars.
- The fraction of those stars which are orbited by planets.
- The number of Earth-like worlds per planetary system.
- The fraction of planets where intelligent life develops.
- The fraction of possible communicative planets.
- The "lifetime" of possible communicative civilizations.

Drake used the equation to estimate that there are approximately 10,000 planets in the Milky Way galaxy containing intelligent life with the possible capability of communicating with Earth.

Based on observations from the Hubble Space Telescope, there are at least 125 billion galaxies in the Universe. It is estimated that at least ten percent of all sun-like stars have a system of planets, i.e. there are 6.25×10^{18} stars with planets orbiting them in the Universe. Even if we assume that only one out of a billion of these stars have planets supporting life, there would be some 6.25×10^{9} (billion) life-supporting planetary systems in the Universe.

Extraterrestrial life in the Solar System



Europa, due to the possibility of an ocean under its icy crust, might host some form of microbial life.

Many bodies in the Solar System have been suggested as being capable of containing conventional organic life. The most commonly suggested ones are listed below; of these, five of the ten are moons, and are thought to have large bodies of underground liquid (streams), where life may have evolved in a way similar to biological communities surrounding deep sea vents.

- Mars — Life on Mars has been long speculated. Liquid water is widely thought to have existed on Mars in the past, and there may still be liquid water beneath the surface. Methane was found in the atmosphere of Mars. By July 2008, laboratory tests aboard NASA's Phoenix Mars Lander had identified water in a soil sample. The lander's robotic arm delivered the sample to an instrument which identifies vapors produced by the heating of samples. Recent photographs from the Mars Global Surveyor show evidence of recent (i.e. within 10 years) flows of a liquid on the Red Planet's frigid surface.
- Mercury — The MESSENGER expedition to Mercury has discovered that a large amount of water exists in its exosphere.
- Venus — Recently, scientists have speculated on the existence of microbes in the stable cloud layers 50 km above the surface, evidenced by hospitable climates and chemical disequilibrium.

- Jupiter — Carl Sagan and others in the 1960s and 70s computed conditions for hypothetical amino acid-based macroscopic life in the atmosphere of Jupiter, based on observed conditions of this atmosphere. These investigations inspired some science fiction stories.
- Ganymede (Largest moon of Jupiter) — Possible underground ocean.
- Callisto (Moon of Jupiter) — Possible underground ocean.
- Europa (Moon of Jupiter) — Europa may contain liquid water beneath its thick ice layer. It is possible that vents on the bottom of the ocean warm the ice, so liquid could exist beneath the ice layer, perhaps capable of supporting microbes and simple plants, just like in Earth's hydrothermal vents.
- Titan (Largest moon of Saturn) — The only known moon with a significant atmosphere. Data from the Cassini-Huygens mission refuted the hypothesis of a global hydrocarbon ocean, but later demonstrated the existence of liquid hydrocarbon lakes in the polar regions—the first liquid lakes discovered outside of Earth. Analysis of data from the mission has uncovered aspects of atmospheric chemistry near the surface which are consistent with —but do not prove— the hypothesis that organisms there are consuming hydrogen, acetylene and ethane, and producing methane.
- Enceladus (Moon of Saturn) — Geothermal activity, water vapor. Possible under-ice oceans heated by tidal effects.

Numerous other bodies have been suggested as potential hosts for microbial life. Fred Hoyle has proposed that life might exist on comets, as some Earth microbes managed to survive on a lunar probe for many years (later considered doubtful as sterile procedures may not have been fully followed). However, it is considered highly unlikely that complex multicellular organisms of the conventional chemistry of terrestrial life (i.e. animals and plants) could exist under these living conditions.

Even if microbial extraterrestrial life were found on another body in the Solar System, it would still need to be proven that such life did not originate from Earth in the recent or distant past. For example, an alternate explanation for the hypothetical existence of microbial life on Titan has already been formally proposed —theorizing that microorganisms could have left Earth when it suffered a massive asteroid or comet impact (such as the impact that created Chicxulub crater only 65 mya), and survived a journey through space to land on Titan 1 million years later. The Living Interplanetary Flight Experiment, developed by the Planetary Society and due to be launched in 2011, has been designed to test similar theories.

Chapter- 2

Drake Equation

The **Drake equation** (sometimes called the **Green Bank equation** or the **Green Bank Formula**) is an equation used to estimate the number of detectable extraterrestrial civilizations in the Milky Way galaxy. It is used in the fields of exobiology and the search for extraterrestrial intelligence (SETI). The equation was devised by Frank Drake, Emeritus Professor of Astronomy and Astrophysics at the University of California, Santa Cruz.

History

In 1960, Frank Drake conducted the first search for radio signals from extraterrestrial civilizations at the National Radio Astronomy Observatory in Green Bank, West Virginia. Soon thereafter, the National Academy of Sciences asked Drake to convene a meeting on detecting extraterrestrial intelligence. The meeting was held at the Green Bank facility in 1961. The equation that bears Drake's name arose out of his preparations for the meeting:

As I planned the meeting, I realized a few day[s] ahead of time we needed an agenda. And so I wrote down all the things you needed to know to predict how hard it's going to be to detect extraterrestrial life. And looking at them it became pretty evident that if you multiplied all these together, you got a number, N, which is the number of detectable civilizations in our galaxy. This, of course, was aimed at the radio search, and not to search for primordial or primitive life forms.

– Frank Drake

This meeting established SETI as a scientific discipline. The meeting's dozen participants — astronomers, physicists, biologists, social scientists, and industry leaders — became known as the "Order of the Dolphin". The Green Bank meeting has been commemorated by a plaque at the site.

The Drake equation is closely related to the Fermi paradox in that Drake suggested that a large number of extraterrestrial civilizations would form, but that the lack of evidence of such civilizations (the Fermi paradox) suggests that technological civilizations tend to

disappear rather quickly. This theory often stimulates an interest in identifying and publicizing ways in which humanity could destroy itself, and then counters with hopes of avoiding such destruction and eventually becoming a space-faring species. A similar argument is The Great Filter, which notes that since there are no observed extraterrestrial civilizations, despite the vast number of stars, then some step in the process must be acting as a filter to reduce the final value. According to this view, either it is very hard for intelligent life to arise, or the lifetime of such civilizations must be relatively short.

Carl Sagan, a great proponent of SETI, quoted the formula often and as a result the formula is sometimes mislabeled as "The Sagan Equation."

The equation

The Drake equation states that:

$$N = R^* \cdot f_p \cdot n_e \cdot f_\ell \cdot f_i \cdot f_c \cdot L$$

where:

N = the number of civilizations in our galaxy with which communication might be possible;

and

R^* = the average rate of star formation per year in our galaxy
f_p = the fraction of those stars that have planets
n_e = the average number of planets that can potentially support life per star that has planets
f_ℓ = the fraction of the above that actually go on to develop life at some point
f_i = the fraction of the above that actually go on to develop intelligent life
f_c = the fraction of civilizations that develop a technology that releases detectable signs of their existence into space
L = the length of time for which such civilizations release detectable signals into space.

Alternative expression

The number of stars in the galaxy now, N^*, is related to the star formation rate R^* by

$$N^* = \int_0^{T_g} R^*(t)dt,$$

where T_g = the age of the galaxy. Assuming for simplicity that R^* is constant, then $N^* = R^* \cdot T_g$ and the Drake equation can be rewritten into an alternate form phrased in terms of the more easily observable value, N^*.

$$N = N^* \cdot f_p \cdot n_e \cdot f_\ell \cdot f_i \cdot f_c \cdot L/T_g$$

R factor

One can question why the number of civilizations should be proportional to the star formation rate, though this makes technical sense. (The product of all the terms except L tells how many new communicating civilizations are born each year. Then you multiply by the lifetime to get the expected number. For example, if an average of 0.01 new civilizations are born each year, and they each last 500 years on the average, then on the average 5 will exist at any time.) The original Drake Equation can be extended to a more realistic model, where the equation uses not the number of stars that are forming now, but those that were forming several billion years ago. The alternate formulation, in terms of the number of stars in the galaxy, is easier to explain and understand, but implicitly assumes the star formation rate is constant over the life of the galaxy.

Elaborations of the Drake Equation

As many observers have pointed out, the Drake equation is a very simple model that does not include potentially relevant parameters. David Brin states:

[The Drake Equation] merely speaks of the number of sites at which ETIs *spontaneously arise*. It says nothing directly about the contact cross-section between an ETIS and contemporary human society.

Because it is the contact cross-section that is of interest to the SETI community, many additional factors and modifications of the Drake equation have been proposed. These include the number of times a civilization might re-appear on the same planet, the number of nearby stars that might be colonized and form sites of their own, and other factors.

Colonization

Brin has proposed generalizing the Drake Equation to include additional effects of alien civilizations colonizing other star systems. Each original site expands with an expansion velocity v, and establishes additional sites that survive for a lifetime L'. The result is a more complex set of 3 equations.

Reappearance number

The Drake equation may furthermore be multiplied by *how many times* an intelligent civilization may occur on planets where it has happened once. Even if an intelligent civilization reaches the end of its lifetime after, for example, 10,000 years, life may still prevail on the planet for billions of years, permitting the next civilization to evolve. Thus, several civilizations may come and go during the lifespan of one and the same planet. Thus, if n_r is the average number of times a new civilization *re*appears on the same planet

where a previous civilization once has appeared and ended, then the total number of civilizations on such a planet would be $(1+n_r)$, which is the actual *reappearance factor* added to the equation.

The factor depends on what generally is the cause of civilization extinction. If it is generally by temporary uninhabitability, for example a nuclear winter, then n_r may be relatively high. On the other hand, if it is generally by permanent uninhabitability, such as stellar evolution, then n_r may be almost zero.

In the case of total life extinction, a similar factor may be applicable for f_ℓ, that is, *how many times* life may appear on a planet where it has appeared once.

METI factor

Alexander Zaitsev said that to be in a communicative phase and emit dedicated messages are not the same. For example, humans, although being in a communicative phase, are not a communicative civilization; we do not practice such activities as the purposeful and regular transmission of interstellar messages. For this reason, he suggested introducing the METI factor (Messaging to Extra-Terrestrial Intelligence) to the classical Drake Equation. The factor is defined as "The fraction of communicative civilizations with clear and non-paranoid planetary consciousness", or alternatively expressed, the fraction of communicative civilizations that actually engage in deliberate interstellar transmission.

Historical estimates of the parameters

Considerable disagreement on the values of most of these parameters exists, but the values used by Drake and his colleagues in 1961 were:

- $R^* = 10$/year (10 stars formed per year, on the average over the life of the galaxy)
- $f_p = 0.5$ (half of all stars formed will have planets)
- $n_e = 2$ (stars with planets will have 2 planets capable of developing life)
- $f_l = 1$ (100% of these planets will develop life)
- $f_i = 0.01$ (1% of which will be intelligent life)
- $f_c = 0.01$ (1% of which will be able to communicate)
- $L = 10{,}000$ years (which will last 10,000 years)

Drake's values give $N = 10 \times 0.5 \times 2 \times 1 \times 0.01 \times 0.01 \times 10{,}000 = 10$.

The value of R^* is determined from considerable astronomical data, and is the least disputed term of the equation; f_p is less certain, but is still much firmer than the values following. The value of n_e is based on our own solar system, and assumes that two planets had the possibility of having life. This not only has problems with anthropic bias, but also is inconsistent with a f_l of one unless we do find life on Mars. Also, the discovery of numerous gas giants in close orbit with their stars has introduced doubt that life-supporting planets commonly survive the creation of their stellar systems. In addition, most stars in our galaxy are red dwarfs, which flare violently, mostly in X-rays—a

property not conducive to life as we know it (simulations also suggest that these bursts erode planetary atmospheres). The possibility of life on moons of gas giants (such as Jupiter's moon Europa, or Saturn's moon Titan) adds further uncertainty to this figure.

Geological evidence from the Earth suggests that f_l may be very high; life on Earth appears to have begun around the same time as favorable conditions arose, suggesting that abiogenesis may be relatively common once conditions are right. However, this evidence only looks at the Earth (a single model planet), and contains anthropic bias, as the planet of study was not chosen randomly, but by the living organisms that already inhabit it (ourselves). Also countering this argument is that there is no evidence for abiogenesis occurring more than once on the Earth—that is, all terrestrial life stems from a common origin. If abiogenesis were more common it would be speculated to have occurred more than once on the Earth. In addition, from a classical hypothesis testing standpoint, there are zero degrees of freedom, permitting no valid estimates to be made. If life were to be found on Mars that developed independently from life on Earth it would imply a value for f_l close to one. While this would improve the degrees of freedom from zero to one, there would remain a great deal of uncertainty on any estimate due to the small sample size, and the chance they are not really independent.

Similar arguments of bias can be made regarding f_i and f_c by considering the Earth as a model: intelligence with the capacity of extraterrestrial communication occurs only in one species in the 4 billion year history of life on Earth. If generalized, this means only relatively old planets may have intelligent life capable of extraterrestrial communication. Again this model has a large anthropic bias and there are still zero degrees of freedom. Note that the capacity and willingness to participate in extraterrestrial communication has come relatively "quickly", with the Earth having only an estimated 100,000 year history of intelligent human life, and less than a century of technological ability.

f_i, f_c and L, like f_l, are also guesses. Estimates of f_i have been affected by discoveries that the solar system's orbit is circular in the galaxy, at such a distance that it remains out of the spiral arms for hundreds of millions of years (evading radiation from novae). Also, Earth's large moon may aid the evolution of life by stabilizing the planet's axis of rotation. In addition, while it appears that life developed soon after the formation of Earth, the Cambrian explosion, in which a large variety of multicellular life forms came into being, occurred a considerable amount of time after the formation of Earth, which suggests the possibility that special conditions were necessary. Some scenarios such as the Snowball Earth or research into the extinction events have raised the possibility that life on Earth is relatively fragile. Again, the controversy over life on Mars is relevant since a discovery that life did form on Mars but ceased to exist would affect estimates of these terms.

The astronomer Carl Sagan speculated that all of the terms, except for the lifetime of a civilization, are relatively high and the determining factor in whether there are large or small numbers of civilizations in the universe is the civilization lifetime, or in other words, the ability of technological civilizations to avoid self-destruction. In Sagan's case,

the Drake equation was a strong motivating factor for his interest in environmental issues and his efforts to warn against the dangers of nuclear warfare.

By plugging in apparently "plausible" values for each of the parameters above, the resultant value of N can be made greater than 1. This has provided considerable motivation for the SETI movement. However, we have no evidence for extraterrestrial civilizations. This conflict is often called the Fermi paradox, after Enrico Fermi who first asked about our lack of observation of extraterrestrials, and motivates advocates of SETI to continually expand the volume of space in which another civilization could be observed.

Some computations of the Drake equation, given different assumptions:

Current estimates (see below):

> $R^* = 7$/year, $f_p = 0.5$, $n_e = 2$, $f_l = 0.33$, $f_i = 0.01$, $f_c = 0.01$, and $L = 10{,}000$ years
> $N = 7 \times 0.5 \times 2 \times 0.33 \times 0.01 \times 0.01 \times 10{,}000 = 2.31$ (so two communicative civilizations exist in our galaxy at any given time, on average, plus two hundred more that are not trying to communicate).

But a pessimist might equally well believe that suitable planets are rare, life seldom becomes intelligent, and intelligent civilizations do not last very long:

> $R^* = 10$/year, $f_p = 0.5$, $n_e = 0.01$, $f_l = 0.13$, $f_i = 0.001$, $f_c = 0.01$, and $L = 1000$ years
> $N = 10 \times 0.5 \times 0.01 \times 0.13 \times 0.001 \times 0.01 \times 1000 = 0.000065$ (we are almost surely alone in our galaxy).

Alternatively, making some more optimistic assumptions, assuming that planets are common, life always arises when planets are favorable, 10% of civilizations become willing and able to communicate, and then spread through their local star systems for 100,000 years (a very short period in geologic time):

> $R^* = 20$/year, $f_p = 0.5$, $n_e = 2$, $f_l = 1$, $f_i = 0.1$, $f_c = 0.1$, and $L = 100{,}000$ years
> $N = 20 \times 0.5 \times 2 \times 1 \times 0.1 \times 0.1 \times 100{,}000 = 20{,}000$ (there's quite a few civilizations, although the closest one would still be about 1500 light years away).

Current estimates of the parameters

This section attempts to list best current estimates for the parameters of the Drake equation.

R^* = the rate of star creation in our galaxy

> Estimated by Drake as 10/year. Latest calculations from NASA and the European Space Agency indicate that the current rate of star formation in our galaxy is about 7 per year.

f_p = the fraction of those stars that have planets

Estimated by Drake as 0.5. It is now known from modern planet searches that at least 40% of sun-like stars have planets, and the true proportion may be much higher, since only planets considerably larger than Earth can be detected with current technology. Infra-red surveys of dust discs around young stars imply that 20-60% of sun-like stars may form terrestrial planets. Microlensing surveys, sensitive to planets further from their star, see planets in about 1/3 of systems examined–a lower limit since not all planets are seen. A mid-2010 estimate by Dimitar Sasselov, of the Kepler planet-hunting team estimates the number of terrestrial planets in the Milky Way to be as much as 100 million.

n_e = the average number of planets (satellites may perhaps sometimes be just as good candidates) that can potentially support life per star that has planets

Estimated by Drake as 2, which would imply not only that our solar system is typical but that life could possibly evolve on at least one of Mars, Europa, or Titan. Marcy et al. note that most of the observed planets have very eccentric orbits, or orbit very close to the sun where the temperature is too high for earth-like life. However, several planetary systems that look more solar-system-like are known, such as HD 70642, HD 154345, Gliese 849 or Gliese 581. There may well be other, as yet unseen, earth-sized planets in the habitable zones of these stars. Also, the variety of solar systems that might have habitable zones is not just limited to solar-type stars and earth-sized planets; it is now believed that even tidally locked planets close to red dwarfs might have habitable zones, and some of the large planets detected so far could potentially support life

In early 2008, two different research groups concluded that Gliese 581 d may possibly be habitable. Since about 200 planetary systems are known, this very roughly estimates $n_e > 0.005$. In 2010, researchers announced the discovery of Gliese 581 g, a 3.1 Earth-mass planet in near the middle of the habitable zone of Gliese 581, and a strong candidate for being the first known Earth-like habitable planet. Given the closeness of the planet's star, and the number of stars examined to the level of detail needed to find such planets, they estimate ε_{Earth}, or the fraction of stars with Earth-like planets, as 10-20%.

Using different criteria, Lineweaver has also determined that about 10% of star systems in the Galaxy are hospitable to life, by having heavy elements, being far from supernovae and being stable for a sufficient time.

NASA's Kepler mission was launched on March 6, 2009. Unlike previous searches, it is sensitive to planets as small as Earth, and with orbital periods as long as a year. If successful, Kepler should provide a much better estimate of the number of planets per star that are found in the habitable zone.

Even if planets are in the habitable zone, however, the number of planets with the right proportion of elements may be difficult to estimate. Also, the Rare Earth hypothesis, which posits that conditions for intelligent life are quite rare, has advanced a set of arguments based on the Drake equation that the number of

planets or satellites that could support life is small, and quite possibly limited to Earth alone; in this case, the estimate of n_e would be infinitesimal.

f_l = the fraction of the above that actually go on to develop life

Estimated by Drake as 1. The combination of this with n_e=2 implies that he believes it is likely that life has evolved on one other planet in the solar system (presumably Mars, Europa, or Titan), in addition to Earth.
In 2002, Charles H. Lineweaver and Tamara M. Davis (at the University of New South Wales and the Australian Centre for Astrobiology) estimated f_l as > 0.13 on planets that have existed for at least one billion years using a statistical argument based on the length of time life took to evolve on Earth.

f_i = the fraction of the above that actually go on to develop intelligent *life*

Estimated by Drake as 0.01 based on little or no evidence. This value remains particularly controversial. Those who favor a low value, such as the biologist Ernst Mayr, point out that of the billions of species that have existed on Earth, only one has become intelligent and from this infer a tiny value for f_i. Those who favor higher values note the generally increasing complexity of life and conclude that the eventual appearance of intelligence might be inevitable, implying an f_i approaching 1. Skeptics point out that the large spread of values in this term and others make all estimates unreliable.

f_c = the fraction of the above that are willing and able to communicate

Estimated by Drake as 0.01. There is considerable speculation why a civilization might exist but choose not to communicate, but there is no hard data.

L = the expected lifetime of such a civilization for the period that it can communicate across interstellar space

Estimated by Drake as 10,000 years.
In an article in *Scientific American*, Michael Shermer estimated L as 420 years, based on compiling the durations of sixty historical civilizations. Using twenty-eight civilizations more recent than the Roman Empire he calculates a figure of 304 years for "modern" civilizations. It could also be argued from Michael Shermer's results that the fall of most of these civilizations was followed by later civilizations that carried on the technologies, so it's doubtful that they are separate civilizations in the context of the Drake equation. In the expanded version, including *reappearance number*, this lack of specificity in defining single civilizations doesn't matter for the end result, since such a civilization turnover could be described as an increase in the *reappearance number* rather than increase in L, stating that a civilization reappears in the form of the succeeding cultures. Furthermore, since none could communicate over interstellar space, the method of comparing with historical civilizations could be regarded as invalid.

> David Grinspoon has argued that once a civilization has developed it might overcome all threats to its survival. It will then last for an indefinite period of time, making the value for L potentially billions of years. If this is the case, then the galaxy has been steadily accumulating advanced civilizations since it formed.

Values based on the above estimates,

> $R^* = 7$/year, $f_p = 0.5$, $n_e = 2$, $f_l = 0.33$, $f_i = 0.01$, $f_c = 0.01$, and $L = 10000$ years

result in

> $N = 7 \times 0.5 \times 2 \times 0.33 \times 0.01 \times 0.01 \times 10000 = 2.31$

James Kasting, in his book "How To Find A Habitable Planet", gives the equation as $N = N_g \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot f_L$, where the first term on the right hand side of the equation is the number of stars in the galaxy. He estimates the first three terms at 4×10^9. He then uses Carl Sagan's figures for the next three terms, disclaiming responsibility, and arrives at approximately 10 to the seventh power as an estimate, not considering the final term, f_L, which is the fraction of a planet's lifetime during which it supports a technical civilization. He notes that this is the most uncertain factor in the equation.

Criticism

Criticism of the Drake equation follows mostly from the observation that several terms in the equation are largely or entirely based on conjecture. Thus the equation cannot be used to draw firm conclusions of any kind. As T.J. Nelson states:

The Drake equation consists of a large number of probabilities multiplied together. Since each factor is guaranteed to be somewhere between 0 and 1, the result is also guaranteed to be a reasonable-looking number between 0 and 1. Unfortunately, all the probabilities are completely unknown, making the result worse than useless.

Likewise, in a 2003 lecture at Caltech, Michael Crichton, a science fiction author, stated:

The problem, of course, is that none of the terms can be known, and most cannot even be estimated. The only way to work the equation is to fill in with guesses. [...] As a result, the Drake equation can have any value from "billions and billions" to zero. An expression that can mean anything means nothing. Speaking precisely, the Drake equation is literally meaningless...

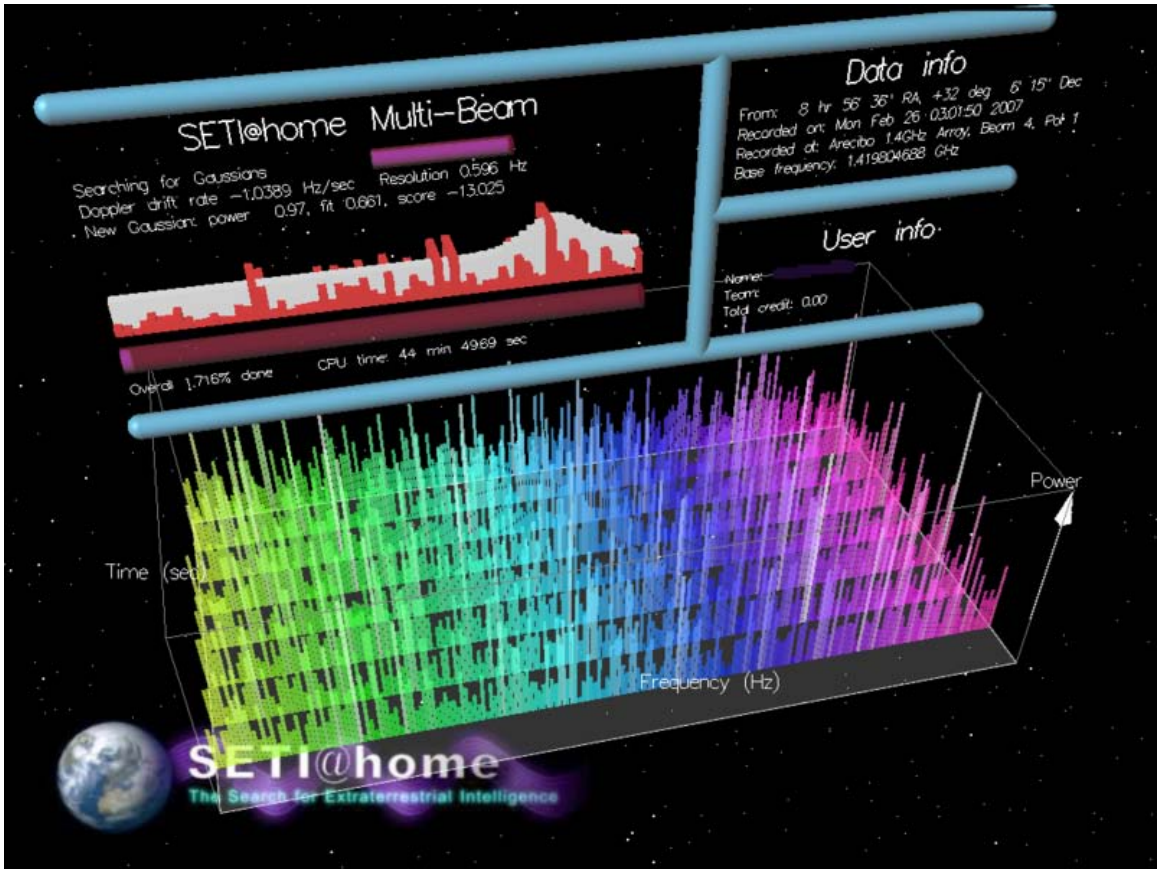
Another objection is that the very form of the Drake equation assumes that civilizations arise and then die out within their original solar systems. If interstellar colonization is possible, then this assumption is invalid, and the equations of population dynamics would apply instead.

One reply to such criticisms is that even though the Drake equation currently involves speculation about unmeasured parameters, it was not meant to be science, but intended as a way to stimulate dialog on these topics. Then the focus becomes how to proceed experimentally. Indeed, Drake originally formulated the equation merely as an agenda for discussion at the Green Bank conference.

Another reply to such criticisms is that the Drake Equation is a Fermi problem which involves the multiplication of several estimated factors, and such calculations (e.g. the number of piano tuners in Chicago) will *probably* be more accurate than might be first supposed (assuming that there is no consistent bias in the estimated factors). This is because if there is no consistent bias, then there will probably (with a binomial distribution) be some factors that are estimated too high and other factors that are estimated too low, and such errors will partially cancel each other out.

Chapter- 3

SETI

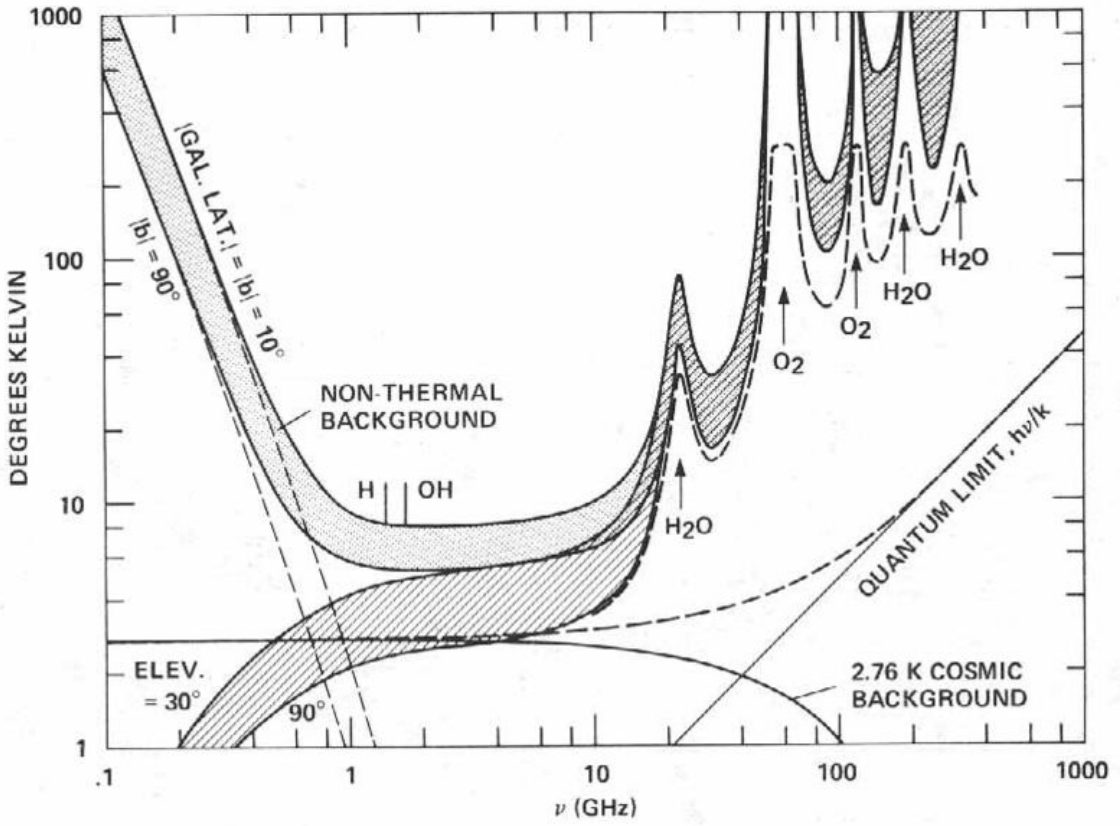


Screen shot of the screensaver for SETI@home, a distributed computing project in which volunteers donate idle computer power to analyze radio signals for signs of extraterrestrial intelligence

Search for Extra-Terrestrial Intelligence (**SETI**) is the collective name for a number of activities people undertake to search for intelligent extraterrestrial life. SETI projects use scientific methods to search for electromagnetic transmissions from civilizations on distant planets. The United States government contributed to earlier SETI projects, but recent work has been primarily funded by private sources.

There are great challenges in searching across the cosmos for a first transmission that could be characterized as intelligent, since its direction, spectrum and method of communication are all unknown beforehand. SETI projects necessarily make assumptions to narrow the search, and thus no exhaustive search has been conducted so far. Of course, the first great assumption is that other intelligent species, whose civilizations could be hundreds of thousands, or even millions of years old, and so with technologies far beyond our imagination, use EMR for communication at all.

Radio experiments



Microwave window as seen by a ground based system. From NASA report SP-419: SETI - the Search for Extraterrestrial Intelligence

Many radio frequencies penetrate our atmosphere quite well, and this led to radio telescopes that investigate the cosmos using large radio antennas. Furthermore, the earth emits considerable radio radiation as a byproduct of communications such as TV and radio, and these radiations would be easy to recognize as artificial due to their repetitive nature and narrow bandwidths. If this is typical, one way of discovering an extraterrestrial civilization might be to detect non-natural radio emissions from a location outside our Solar System.

Early work

As early as 1896, Nikola Tesla suggested that radio could be used to contact extraterrestrial life. In 1899 while investigating atmospheric electricity using a Tesla coil receiver in his Knob Hill lab Tesla observed repetitive signals, substantially different from the signals noted from storms and Earth noise, that he interpreted as being of extraterrestrial origin. He later recalled the signals appeared in groups of one, two, three, and four clicks together. Tesla thought the signals were coming from Mars. Analysis of Tesla's research has ranged from suggestions that Tesla detected nothing (he simply was misunderstanding the new technology he was working with) to claims that Tesla may have been observing naturally occurring Jovian plasma torus signals. In the early 1900s, Guglielmo Marconi, Lord Kelvin, and David Peck Todd also stated their belief that radio could be used to contact Martians (with Marconi stating that his stations had also picked up potential Martian signals).

On August 21–23, 1924, Mars entered an opposition closer to Earth than any time in a century before or since. In the United States, a "National Radio Silence Day" was promoted during a 36-hour period from the 21-23, with all radios quiet for five minutes on the hour, every hour. At the United States Naval Observatory, a radio receiver was lifted 3 kilometers above the ground in a dirigible tuned to a wavelength between 5 and 6 kilometers, using a "radio-camera" developed by Amherst College and Charles Francis Jenkins. The program was led by David Peck Todd with the military assistance of Admiral Edward W. Eberle (Chief of Naval Operations) and William F. Friedman (chief cryptographer of the US Army, who was assigned to translate any potential Martian messages).

A 1959 paper by Cocconi and Morrison first pointed out the possibility of searching the microwave spectrum, and proposed frequencies and a set of initial targets.

In 1960, Cornell University astronomer Frank Drake performed the first modern SETI experiment, named "Project Ozma", after the Queen of Oz in L. Frank Baum's fantasy books. Drake used a 26-meter-diameter radio telescope at Green Bank, West Virginia, to examine the stars Tau Ceti and Epsilon Eridani near the 1.420 gigahertz marker frequency, a region of the radio spectrum dubbed the "water hole" due to its proximity to the H and OH spectral lines. A 400 kilohertz band was scanned around the marker frequency, using a single-channel receiver with a bandwidth of 100 hertz. The information was stored on tape for off-line analysis. He found nothing of great interest, but has continued a pro active involvement in the search for life beyond earth - for 50 years.

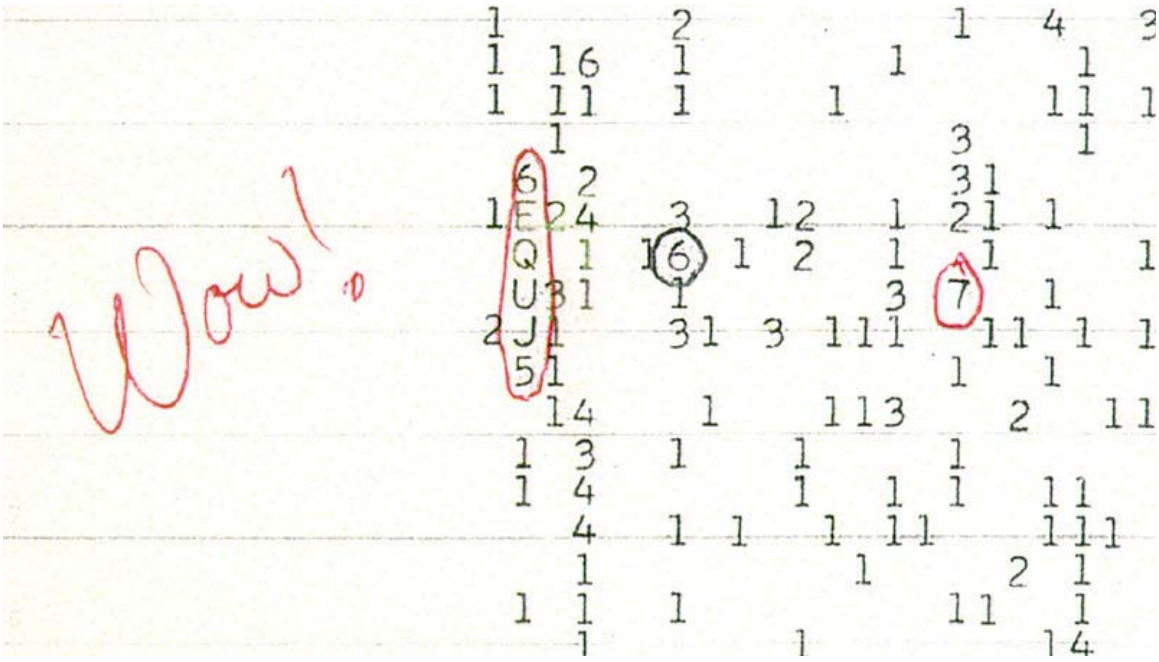
The first SETI conference took place at Green Bank in 1961. The Soviets took a strong interest in SETI during the 1960s and performed a number of searches with omnidirectional antennas in the hope of picking up powerful radio signals. American astronomer Carl Sagan and Soviet astronomer Iosif Shklovskii together wrote the pioneering book in the field, *Intelligent Life in the Universe* which was published in 1966.

The first Kraus-style radio telescope was powered up in 1963. It was 360 feet (110 m) wide, 500 feet (150 m) long, and 70 feet (21 m) high. In the March 1955 issue of Scientific American, John Kraus described a concept to scan the cosmos for natural radio signals using a flat-plane radio telescope equipped with a parabolic reflector. Within two years, his concept was approved for construction by Ohio State University. With $71,000 total in grants from the National Science Foundation, construction began on a 20-acre plot in Delaware, Ohio. This Ohio State University radio telescope was called Big Ear. Later, it began the world's first continuous SETI program, called the Ohio State University SETI program.

View of Arecibo Observatory in Puerto Rico with its 300 m dish- the world's largest. A small fraction of its observation time is devoted to SETI searches.

In 1971, NASA funded a SETI study that involved Drake, Bernard Oliver of Hewlett-Packard Corporation, and others. The resulting report proposed the construction of an Earth-based radio telescope array with 1,500 dishes known as "Project Cyclops". The price tag for the Cyclops array was $10 billion USD. Cyclops was not built, but the report formed the basis of much SETI work that followed.

In 1974, a largely symbolic attempt was made at the Arecibo Observatory to send a message to other worlds. It was sent towards the globular star cluster M13, which is 25,000 light years from Earth.



The WOW! Signal
Credit: The Ohio State University Radio Observatory and the North American AstroPhysical Observatory (NAAPO).

The OSU SETI program gained fame on August 15, 1977 when Jerry Ehman, a project volunteer, witnessed a startlingly strong signal received by the telescope. He quickly circled the indication on a printout and scribbled the phrase “Wow!” in the margin. This signal, dubbed the *Wow! signal*, is considered by some to be the most likely candidate from an artificial, extraterrestrial source ever discovered, but it has not been detected again in several additional searches.

In 1979 the University of California, Berkeley launched a SETI project named "Search for Extraterrestrial Radio Emissions from Nearby Developed Intelligent Populations (SERENDIP)". In 1986, UC Berkeley initiated their second SETI effort, SERENDIP II, and has continued with four more SERENDIP efforts to the present day. The latest incarnation of the SERENDIP project is SERENDIP V.v, a commensal all-sky survey using the Arecibo radio telescope began in June 2009.

Sentinel, META, and BETA

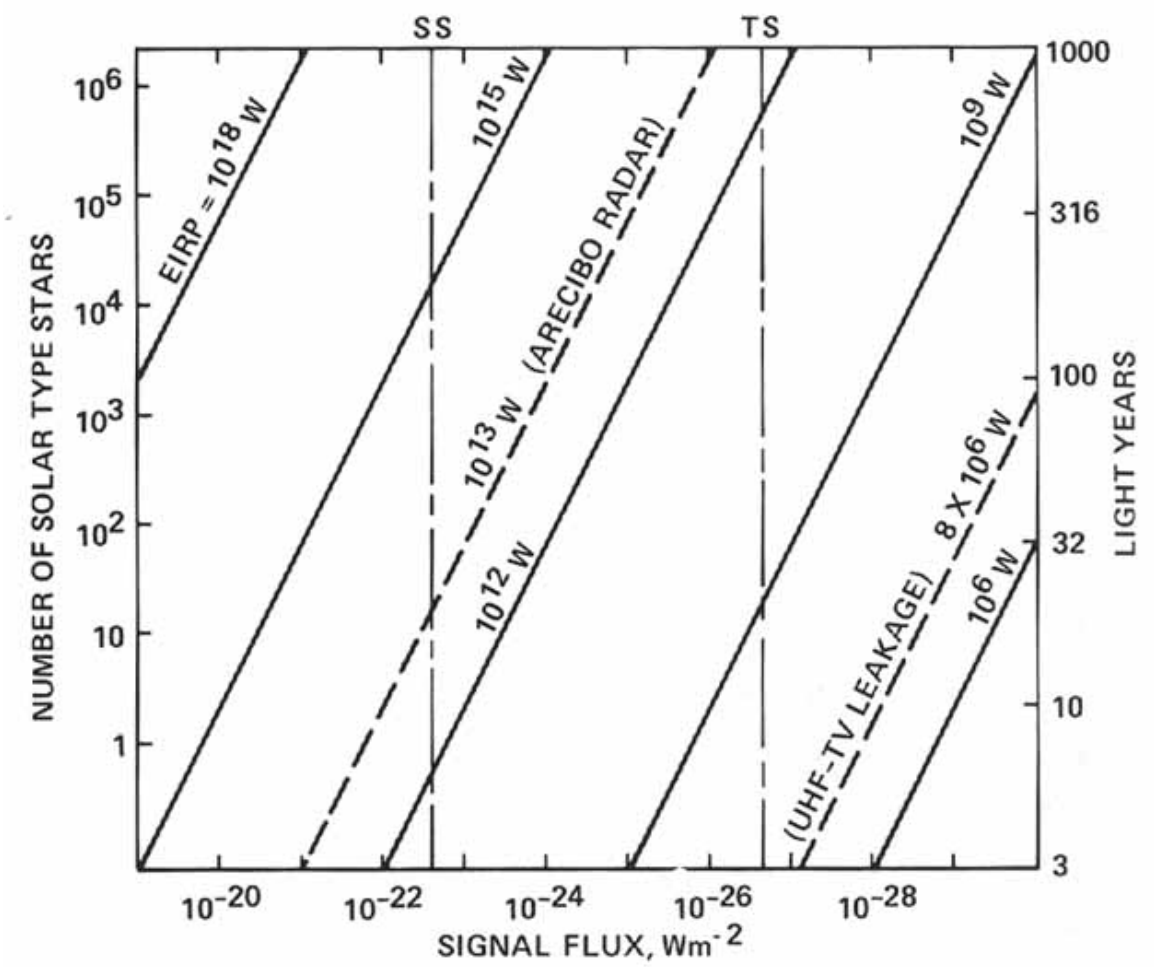
In 1980, Carl Sagan, Bruce Murray, and Louis Friedman founded the U.S. Planetary Society, partly as a vehicle for SETI studies.

In the early 1980s, Harvard University physicist Paul Horowitz took the next step and proposed the design of a spectrum analyzer specifically intended to search for SETI transmissions. Traditional desktop spectrum analyzers were of little use for this job, as they sampled frequencies using banks of analog filters and so were restricted in the number of channels they could acquire. However, modern integrated-circuit digital signal processing (DSP) technology could be used to build autocorrelation receivers to check far more channels. This work led in 1981 to a portable spectrum analyzer named "Suitcase SETI" that had a capacity of 131,000 narrow band channels. After field tests that lasted into 1982, Suitcase SETI was put into use in 1983 with the 26-meter Harvard/Smithsonian radio telescope at Harvard, Massachusetts. This project was named "Sentinel", and continued into 1985.

Even 131,000 channels weren't enough to search the sky in detail at a fast rate, so Suitcase SETI was followed in 1985 by Project "META", for "Megachannel Extra-Terrestrial Assay". The META spectrum analyzer had a capacity of 8.4 million channels and a channel resolution of 0.05 hertz. An important feature of META was its use of frequency doppler shift to distinguish between signals of terrestrial and extraterrestrial origin. The project was led by Horowitz with the help of the Planetary Society, and was partly funded by movie maker Steven Spielberg. A second such effort, META II, was begun in Argentina in 1990 to search the southern sky. META II is still in operation, after an equipment upgrade in 1996.

The follow-on to META was named "BETA", for "Billion-channel ExtraTerrestrial Assay", and it commenced observation on October 30, 1995. The heart of BETA's processing capability consisted of 63 dedicated fast Fourier transform (FFT) engines, each capable of performing a 2^{22}-point complex FFTs in two seconds, and 21 general-purpose personal computers equipped with custom digital signal processing boards. This allowed BETA to receive 250 million simultaneous channels with a resolution of 0.5 hertz per channel. It scanned through the microwave spectrum from 1.400 to 1.720 gigahertz in eight hops, with two seconds of observation per hop. An important capability of the BETA search was rapid and automatic re-observation of candidate signals, achieved by observing the sky with two adjacent beams, one slightly to the east and the other slightly to the west. A successful candidate signal would first transit the east beam, and then the west beam and do so with a speed consistent with Earth's sidereal rotation rate. A third receiver observed the horizon to veto signals of obvious terrestrial origin. On March 23, 1999 the 26-meter radio telescope on which Sentinel, META and BETA were based was blown over by strong winds and seriously damaged. This forced the BETA project to cease operation.

MOP and Project Phoenix



Sensitivity vs range for SETI radio searches. The diagonal lnes show transmitters of different effective powers. The X axis is the sensitivity of the search. The Y axis on the right is the range in light years, and on the left is the number of sun-like stars within this range. The vertical line labeled SS is the typical sensitivity achieved by a full sky search, such as BETA above. The vertical line labeled TS is the typical sensitivity achieved by a targeted search such as Phoenix.

In 1992, the U.S. government funded an operational SETI program, in the form of the NASA Microwave Observing Program (MOP). MOP was planned as a long-term effort to conduct a general survey of the sky and also carry out targeted searches of 800 specific nearby stars. MOP was to be performed by radio antennas associated with the NASA Deep Space Network, as well as the 140-foot (43 m) radio telescope of the National Radio Astronomy Observatory at Green Bank, West Virginia and the 1,000-foot (300 m) radio telescope at the Arecibo Observatory in Puerto Rico.. The signals were to be analyzed by spectrum analyzers, each with a capacity of 15 million channels. These spectrum analyzers could be grouped together to obtain greater capacity. Those used in the targeted search had a bandwidth of 1 hertz per channel, while those used in the sky survey had a bandwidth of 30 hertz per channel.

MOP drew the attention of the U.S. Congress, where the program was ridiculed and canceled a year after its start. SETI advocates continued without government funding, and in 1995 the nonprofit SETI Institute of Mountain View, California resurrected the MOP program under the name of Project "Phoenix", backed by private sources of funding. Project Phoenix, under the direction of Jill Tarter, is a continuation of the targeted search program from MOP and studies roughly 1,000 nearby Sun-like stars. From 1995 through March 2004, Phoenix conducted observations at the 64-meter Parkes radio telescope in Australia, the 140-foot (43 m) radio telescope of the National Radio Astronomy Observatory in Green Bank, West Virginia, and the 1,000-foot (300 m) radio telescope at the Arecibo Observatory in Puerto Rico. The project observed the equivalent of 800 stars over the available channels in the frequency range from 1200 to 3000 MHz. The search was sensitive enough to pick up transmitters with 1 GW EIRP to a distance of about 200 light years.

The SETI League and Project Argus

Founded in 1994 in response to the US Congress cancellation of the NASA SETI program, The SETI League, Inc. is a membership-supported nonprofit organization with 1500 members in 62 countries on all seven continents. This grass-roots alliance of amateur and professional radio astronomers is headed by executive director emeritus Prof. H. Paul Shuch, the engineer credited with developing the world's first commercial home satellite TV receiver. Many SETI League members are licensed radio amateurs and microwave experimenters. Others are digital signal processing experts and computer enthusiasts.

The SETI League pioneered the conversion of 3 to 5 metre diameter backyard satellite TV dishes into research-grade radio telescopes of modest sensitivity. The organization concentrates on coordinating a global network of small, amateur-built radio telescopes under Project Argus, an all-sky survey seeking to achieve real-time coverage of the entire sky. Project Argus was conceived as a continuation of the all-sky survey component of the late NASA SETI program (the targeted search having been continued by the SETI Institute's Project Phoenix). There are currently 143 Project Argus radio telescopes operating in 27 countries. Project Argus instruments typically exhibit sensitivity on the order of 10^{-23} Watts/square metre, or roughly equivalent to that achieved by the Ohio State University Big Ear radio telescope in 1977, when it detected the landmark "Wow!" candidate signal.

The name "Argus" derives from the mythical Greek guard-beast who had 100 eyes, and could see in all directions at once. In the SETI context, the name has been used for radio telescopes in fiction (Arthur C. Clarke, *"Imperial Earth"*; Carl Sagan, *"Contact"*), was the name initially used for the NASA study ultimately known as "Cyclops," and is the name given to an omnidirectional radio telescope design being developed at the Ohio State University.

SETI@home

SETI@home logo

SETI@home is a popular volunteer distributed computing project that was launched by the University of California, Berkeley in May 1999. It was originally funded by The Planetary Society and Paramount Pictures, and later by the state of California. The project is run by director David P. Anderson and chief scientist Dan Werthimer. Any individual can become involved with SETI research by downloading the Berkeley Open Infrastructure for Network Computing (BOINC) software program, attaching to the SETI@home project, and allowing the program to run as a background process that uses idle computer power. The SETI@home program itself runs signal analysis on a "work unit" of data recorded from the central 2.5 MHz wide band of the SERENDIP IV instrument. After computation on the work unit is complete, the results are then automatically reported back to SETI@home servers at UC Berkeley. As of June 28, 2009 the SETI@home project has over 180,000 active participants volunteering a total of over 290,000 computers. These computers give SETI@home an average computational power of 617 teraFLOPS. Radio source SHGb02+14a is the most interesting signal analyzed to date.

Allen Telescope Array

The SETI Institute is now collaborating with the Radio Astronomy Laboratory at UC Berkeley to develop a specialized radio telescope array for SETI studies, something like a mini-Cyclops array. The new array concept is named the "Allen Telescope Array" (ATA) (formerly, One Hectare Telescope [1HT]) after the project's benefactor Paul Allen. Its sensitivity will be equivalent to a single large dish more than 100 meters in diameter. The array is being constructed at the Hat Creek Observatory in rural northern California.

The full array is planned to consist of 350 or more Gregorian radio dishes, each 6.1 meters (20 ft) in diameter. These dishes are the largest producible with commercially available satellite television dish technology. The ATA was planned for a 2007 completion date, at a very modest cost of $25 million USD. The SETI Institute provides money for building the ATA while UC Berkeley designs the telescope and provides operational funding. Berkeley astronomers will use the ATA to pursue other deep space radio observations. The ATA is intended to support a large number of simultaneous observations through a technique known as "multibeaming", in which DSP technology is used to sort out signals from the multiple dishes. The DSP system planned for the ATA is extremely ambitious.

The first portion of the array became operational in October 2007 with 42 antennas. Completion of the full 350 element array will depend on funding and the technical results from the 42-element sub-array.

CNET published an article and pictures about the Allen Telescope Array (ATA) on December 12, 2008.

SETI Net

SETI Net is a private search system created by a single individual. It is closely affiliated with the SETI League and is one of the project Argus stations (DM12jw).

The SETI Net station consists of off-the-shelf, consumer-grade electronics to minimize cost and to allow this design to be replicated as simply as possible. It has a 3-meter parabolic antenna that can be directed in azimuth and elevation, an LNA that covers the 1420 MHz spectrum, a receiver to reproduce the wideband audio, and a standard PC as the control device and for deploying the detection algorithms.

The antenna can be pointed and locked to one sky location, enabling the system to integrate on it for long periods. Currently the Wow! signal area is being monitored when it is above the horizon, but all search data are collected and made available on the internet archive.

SETI Net started operation in the early 1980s as a way to learn about the science of the search, and has developed several software packages for the amateur SETI community. It has provided an astronomical clock, a file manager to keep track of SETI data files, a spectrum analyzer optimized for amateur SETI, remote control of the station from the internet, and other packages.

Realized Interstellar Radio Message Projects

The first Interstellar Radio Message (IRM), "Arecibo Message", was transmitted in Nov, 1974 from Arecibo Radar Telescope. IRMs Cosmic Call, Teen Age Message, Cosmic Call 2, A Message From Earth were transmitted in 1999, 2001, 2003 and 2008 from Evpatoria Planetary Radar.

Additional information presents at: Communication with Extraterrestrial Intelligence, Active SETI, List of interstellar radio messages.

Paper Projects

A large number of any paper projects also exist. For example, directed by Douglas Vakoch at SETI in Mountain View, the Interstellar Message Composition Project is charged with sending messages to extraterrestrials that convey basic scientific or mathematical principles, as well as human altruism. Vackoch's idea is to send a message of reciprocal altruism because hopefully any extraterrestrials would reciprocate with a reply back.

Vakoch has founded "Encoding Altruism", a workshop that started in 2003 in Paris that brings together anthropologists, philosophers, physicists, astronomers, theologians,

musicians, and artists to address the challenge of communicating with extraterrestrials in a language and syntax that would be intelligible to an alien civilization.

Vakoch's most recent research is highlighted through Greater Good Science Center, University of California, Berkeley.

Optical experiments

While most SETI sky searches have studied the radio spectrum, some SETI researchers have considered the possibility that alien civilizations might be using powerful lasers for interstellar communications at optical wavelengths. The idea was first suggested by R. N. Schwartz and Charles Hard Townes in a 1961 paper published in the journal *Nature* titled "Interstellar and Interplanetary Communication by Optical Masers". In 1983, Townes, one of the inventors of the laser, published a detailed study of the idea in the US journal *Proceedings of the National Academy of Sciences*. Most SETI researchers agreed with the idea.

The 1971 Cyclops study discounted the possibility of optical SETI, reasoning that construction of a laser system that could outshine the bright central star of a remote star system would be too difficult.

Some SETI advocates, such as Frank Drake, have suggested that such a judgment was too conservative; early 21st century humans have no means of knowing how a superior technology is communicating or would communicate, and negative results may simply mean humans are making the wrong searches.

There are two problems with optical SETI. The first problem is that lasers are highly "monochromatic", that is, they emit light only on one frequency, making it troublesome to figure out what frequency to look for.

However, according to the uncertainty principle, emitting light in narrow pulses results in a broad spectrum of emission; the spread in frequency becomes higher as the pulse width becomes narrower, making it easier to detect an emission.

The other problem is that while radio transmissions can be broadcast in all directions, lasers are highly directional. This means that a laser beam could be easily blocked by clouds of interstellar dust, and Earth would have to cross its direct line of fire by chance to receive it.

Optical SETI supporters have conducted paper studies of the effectiveness of using contemporary high-energy lasers and a ten-meter focus mirror as an interstellar beacon. The analysis shows that an infrared pulse from a laser, focused into a narrow beam by such a mirror, would appear thousands of times brighter than the Sun to a distant civilization in the beam's line of fire. The Cyclops study proved incorrect in suggesting a laser beam would be inherently hard to see.

Such a system could be made to automatically steer itself through a target list, sending a pulse to each target at a constant rate. This would allow targeting of all Sun-like stars within a distance of 100 light-years. The studies have also described an automatic laser pulse detector system with a low-cost, two-meter mirror made of carbon composite materials, focusing on an array of light detectors. This automatic detector system could perform sky surveys to detect laser flashes from civilizations attempting contact.

In the 1980s, two Soviet researchers conducted a short optical SETI search, but turned up nothing. During much of the 1990s, the optical SETI cause was kept alive through searches by Stuart Kingsley, a dedicated British amateur living in the US state of Ohio.

Several optical SETI experiments are now in progress. A Harvard-Smithsonian group that includes Paul Horowitz designed a laser detector and mounted it on Harvard's 155 centimeter (61 inch) optical telescope. This telescope is currently being used for a more conventional star survey, and the optical SETI survey is "piggybacking" on that effort. Between October 1998 and November 1999, the survey inspected about 2,500 stars. Nothing that resembled an intentional laser signal was detected, but efforts continue. The Harvard-Smithsonian group is now working with Princeton University to mount a similar detector system on Princeton's 91-centimeter (36-inch) telescope. The Harvard and Princeton telescopes will be "ganged" to track the same targets at the same time, with the intent being to detect the same signal in both locations as a means of reducing errors from detector noise.

The Harvard-Smithsonian group is now building a dedicated all-sky optical survey system along the lines of that described above, featuring a 1.8-meter (72-inch) telescope. The new optical SETI survey telescope is being set up at the Oak Ridge Observatory in Harvard, Massachusetts.

The University of California, Berkeley, home of SERENDIP and SETI@home, is also conducting optical SETI searches. One is being directed by Geoffrey Marcy, an extrasolar planet hunter, and involves examination of records of spectra taken during extrasolar planet hunts for a continuous, rather than pulsed, laser signal. The other Berkeley optical SETI effort is more like that being pursued by the Harvard-Smithsonian group and is being directed by Dan Werthimer of Berkeley, who built the laser detector for the Harvard-Smithsonian group. The Berkeley survey uses a 76-centimeter (30-inch) automated telescope at Leuschner Observatory and an older laser detector built by Werthimer.

Probe SETI and SETA experiments

The possibility of using interstellar messenger probes in the search for extraterrestrial intelligence was first suggested by Ronald N. Bracewell in 1960, and the technical feasibility of this approach was demonstrated by the British Interplanetary Society's starship study Project Daedalus in 1978. Starting in 1979, Robert Freitas advanced arguments for the proposition that physical space-probes are a superior mode of interstellar communication to radio signals.

In recognition that any sufficiently advanced interstellar probe in the vicinity of Earth could easily monitor our terrestrial Internet, Invitation to ETI was established by Prof. Allen Tough in 1996, as a Web-based SETI experiment inviting such spacefaring probes to establish contact with humanity. The project's 100 Signatories includes prominent physical, biological, and social scientists, as well as artists, educators, entertainers, philosophers and futurists. Prof. H. Paul Shuch, executive director emeritus of The SETI League, serves as the project's Principal Investigator.

In a 2004 paper , C. Rose and G. Wright showed that inscribing a message in matter and transporting it to an interstellar destination can be enormously more energy efficient than communication using electromagnetic waves if delays larger than light transit time can be tolerated. That said, for simple messages such as "hello," radio SETI could be far more efficient . If energy requirement is used as a proxy for technical difficulty, then a solarcentric Search for Extraterrestrial Artifacts (SETA) may be a useful supplement to traditional radio or optical searches.

Much like the "preferred frequency" concept in SETI radio beacon theory, the Earth-Moon or Sun-Earth libration orbits might therefore constitute the most universally convenient parking places for automated extraterrestrial spacecraft exploring arbitrary stellar systems. A viable long-term SETI program may be founded upon a search for these objects.

In 1979, Freitas and Valdes conducted a photographic search of the vicinity of the Earth-Moon triangular libration points L_4 and L_5, and of the solar-synchronized positions in the associated halo orbits, seeking possible orbiting extraterrestrial interstellar probes, but found nothing to a detection limit of about 14th magnitude. The authors conducted a second, more comprehensive photographic search for probes in 1982 that examined the five Earth-Moon Lagrangian positions and included the solar-synchronized positions in the stable L4/L5 libration orbits, the potentially stable nonplanar orbits near L1/L2, Earth-Moon L_3, and also L_2 in the Sun-Earth system. Again no extraterrestrial probes were found to limiting magnitudes of 17-19th magnitude near L3/L4/L5, 10-18th magnitude for L_1/L_2, and 14-16th magnitude for Sun-Earth L_2.

In June 1983, Valdes and Freitas used the 26 m radiotelescope at Hat Creek Radio Observatory to search for the tritium hyperfine line at 1516 MHz from 108 assorted astronomical objects, with emphasis on 53 nearby stars including all visible stars within a 20 light-year radius. The tritium frequency was deemed highly attractive for SETI work because (1) the isotope is cosmically rare, (2) the tritium hyperfine line is centered in the SETI waterhole region of the terrestrial microwave window, and (3) in addition to beacon signals, tritium hyperfine emission may occur as a byproduct of extensive nuclear fusion energy production by extraterrestrial civilizations. The wideband- and narrowband-channel observations achieved sensitivities of 5-14 x 10^{-21} W/m²/channel and 0.7-2 x 10^{-24} W/m²/channel, respectively, but no detections were made.

Fermi paradox

Italian physicist Enrico Fermi suggested in the 1950s that if technologically advanced civilizations are common in the universe, then they should be detectable in one way or another. (According to those who were there, Fermi either asked "Where are they?" or "Where is everybody?")

The Fermi paradox can be stated more completely as follows:

The size and age of the universe incline us to believe that many technologically advanced civilizations must exist. However, this belief seems logically inconsistent with our lack of observational evidence to support it. Either (1) the initial assumption is incorrect and technologically advanced intelligent life is much rarer than we believe, or (2) our current observations are incomplete and we simply have not detected them yet, or (3) our search methodologies are flawed and we are not searching for the correct indicators.

Possible explanations for the paradox suggest, for example, that while simple life may well be abundant in the universe, intelligent life may be exceedingly rare. In 2000, Peter Ward, professor of Biology and of Earth and Space Sciences at the University of Washington authored a book claiming the Rare Earth hypothesis. In short, the theory claims that the emergence of complex multicellular life (metazoa) on Earth required an extremely unlikely combination of astrophysical and geological events and circumstances. This hypothesis contradicts the principle of mediocrity, which SETI takes as an assumption.

Another suggestion, made by astrophysicist Ray Norris in 2000 (and subsequently by Allen Tough) was that gamma-ray burst events are sufficiently frequent to sterilize vast swaths of galactic real-estate. This idea was subsequently popularized by physicist Arnon Dar, and described in the show *Death Star* on PBS Nova.

Science writer Timothy Ferris has posited that since galactic societies are most likely only transitory, an obvious solution is an interstellar communications network, or a type of library consisting mostly of automated systems. They would store the cumulative knowledge of vanished civilizations and communicate that knowledge through the galaxy. Ferris calls this the "Interstellar Internet", with the various automated systems acting as network "servers".

If such an Interstellar Internet exists, the hypothesis states, communications between servers are mostly through narrow-band, highly directional radio or laser links. Intercepting such signals is, as discussed earlier, very difficult. However, the network could maintain some broadcast nodes in hopes of making contact with new civilizations.

Although somewhat dated in terms of "information culture" arguments, not to mention the obvious technological problems of a system that could work effectively for billions of years and requires multiple lifeforms agreeing on certain basics of communications technologies, this hypothesis is actually testable (see below).

An alternate hypothesis is that evolutionary pressures in many environments favor species which rapidly consume available resources once they achieve dominance. By the time they have achieved sufficient technology to come to the notice of other civilizations, they are already well on their way to exhausting the resources of their host planet. Therefore the time period available for communication is finite, and very small compared with planetary timescales.

Message decoding

As soon as a message is determined to be SETI in origin, it would have to be decoded. This poses many technical challenges, but the use of existing intellectual tools is probably adequate to help.

The Fourier Transform (FFT) for the other data indicated some strong structures. In the case of the random values, the results of the FFT is rather very noisy and does not show any particular feature.

The combined use of the Fourier Transform and the Kappa test as a first step to decode a message seems to reveal a lot of important information.

Messages formatted as a 2D structure (as an image) seem to have a better chance to be detected as the kappa test and Fourier tests haves shown with the METI messages that have been transmitted by humans.

The application of the Markov process (or the Hidden Markov model) to the deciphering of SETI messages is centred on the idea of probabilistic relation between two words. These symbolic relations can be built into a tree of probabilities applied to a series of words.

From another point of view Markov Models can provide a clearer view of the probability of which one symbol will follow another in a sentence. Markov Models can be used to build tables of association of icons or bitstreams.

The ultimate goal of these information theory and cryptographic processes is to decode and understand the meaning of the message. All the tools contained in cryptanalysis and information theory can help deciphering the format and the logic behind the symbols but nothing more.

The combination of all of these intellectual methods would the beginning of building a lexicon to understand the transmitted message—but these tools will not help understand the meaning of the symbols. If the message is a simple text with questions and inviting us to send our answers, it could not be understood at all.

Public information

The International Academy of Astronautics (IAA) has a long-standing SETI Permanent Study Group (SPSG, formerly called the IAA SETI Committee), which addresses matters of SETI science, technology, and international policy. The SPSG meets in conjunction with the International Astronautical Congress (IAC) held annually at different locations around the world, and sponsors two SETI Symposia at each IAC.

In 2005, the International Academy of Astronautics established the **SETI: Post-Detection Science and Technology Taskgroup** (Chairman, Professor Paul Davies) "to act as a Standing Committee to be available to be called on at any time to advise and consult on questions stemming from the discovery of a putative signal of extraterrestrial intelligent (ETI) origin." It will use, in part, the Rio Scale to evaluate the importance of releasing the information to the public.

Criticism

As various SETI projects have continued, some have criticized early claims by researchers now seen to be too "euphoric" or "optimistic." For example, Peter Schenkel, while remaining a supporter of SETI projects, has written that "[i]n light of new findings and insights, it seems appropriate to put excessive euphoria to rest and to take a more down-to-earth view ... We should quietly admit that the early estimates — that there may be a million, a hundred thousand, or ten thousand advanced extraterrestrial civilizations in our galaxy — may no longer be tenable." Clive Trotman presents some sobering but realistic calculations emphasizing the timeframe dimension.

SETI has also occasionally been the target of criticism by those who suggest that it is a form of pseudoscience. In particular, critics allege that no observed phenomena suggest the existence of extraterrestrial intelligence, and furthermore that the assertion of the existence of extraterrestrial intelligence has no good Popperian criteria for falsifiability.

In response, SETI advocates note, among other things, that the Drake Equation was never a hypothesis, and so never intended to be testable, nor to be "solved"; it was merely a clever representation of the agenda for the world's first scientific SETI meeting in 1961, and it serves as a tool in formulating testable hypotheses. Further, they note that the existence of intelligent life on Earth is a plausible reason to expect it elsewhere, and that individual SETI projects have clearly defined "stop" conditions. Many detractors have not considered the collection and processing of data, the first order of business, and the refining of those data streams, in the case of SETI through algorithm optimization. To justify SETI projects does not require an acceptance of the Drake equation. Science proceeds through hypothesis. If one were to only take what was at face value observable, many scientific phenomena never would have been discovered.

The *search* for extraterrestrial intelligence is not an assertion that extraterrestrial intelligence exists, and conflating the two can be seen as a straw man argument. There is an effort to distinguish the SETI projects from UFOlogy, the study of UFOs, which many consider to be pseudoscience. In *Skeptical Inquirer*, Mark Moldwin argued that the important differences between the two projects were the acceptance of SETI by the

mainstream scientific community and that "[t]he methodology of SETI leads to useful scientific results even in the absence of discovery of alien life."

Some in the UFO community, such as nuclear physicist Stanton Friedman, say there is no basis for the search and it is therefore unscientific. Friedman has challenged SETI specialists to debate the issues, with no takers so far. Examples of objections to SETI include questioning energy requirements as well as why advanced civilizations would use radio.

"Active" SETI

Active SETI (also known as METI = "Messaging to Extra-Terrestrial Intelligence") consists of sending signals into space in the hope that they will be picked up by an alien intelligence. Physicist Stephen Hawking, in his book *A Brief History of Time*, suggests that "alerting" extraterrestrial intelligences of our existence is foolhardy, citing man's history of treating man in meetings of civilizations with a significant technology gap. He suggests that we "lay low".

The concern over SETI was raised by the science journal *Nature* in an editorial in October 2006, which commented on a recent meeting of the International Academy of Astronautics SETI study group. The editor said, "It is not obvious that all extraterrestrial civilizations will be benign, or that contact with even a benign one would not have serious repercussions" (Nature Vol 443 12 Oct 06 p 606). Astronomer and science fiction author David Brin has expressed similar concerns.

As was suggested by Richard Carrigan, a particle physicist at the US Fermi National Accelerator Laboratory in Illinois, 'passive' SETI could also be dangerous in the style of computer viruses.

To lend a quantitative basis to discussions of the risks of transmitting deliberate messages from Earth, the SETI Permanent Study Group of the International Academy of Astronautics adopted in 2007 a new analytical tool, the San Marino Scale. Developed by Prof. Ivan Almar and Prof. H. Paul Shuch, the scale evaluates the significance of transmissions from Earth as a function of signal intensity and information content. Its adoption suggests that not all such transmissions are equal, thus each must be evaluated separately before establishing blanket international policy regarding Active SETI.

But some scientists consider these fears about the dangers of METI as panic and irrational superstition; see, for example, Alexander L. Zaitsev's papers.

Chapter- 4

Communication with Extraterrestrial Intelligence

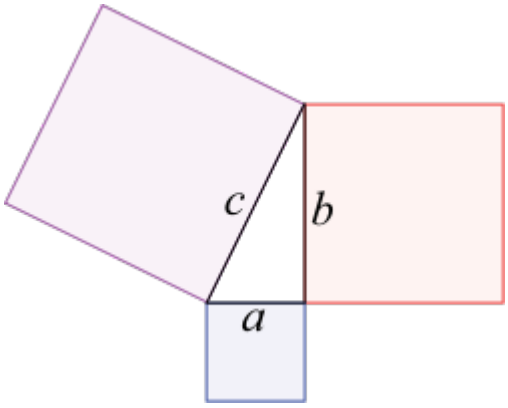
Communication with Extraterrestrial Intelligence (**CETI**) is a branch of SETI research that focuses on composing and deciphering messages that could theoretically be understood by another technological civilization. The best-known CETI experiment was the 1974 Arecibo message composed by Frank Drake and Carl Sagan.

CETI research has focused on four broad areas: mathematical languages, pictorial systems such as the Arecibo message, algorithmic communication systems (ACETI) and computational approaches to detecting and deciphering 'natural' language communication.

History

In the nineteenth century there were many books and articles about the possible inhabitants of other planets. Many people believed that intelligent beings might live on the Moon, Mars, and Venus; but since travel to other planets was not yet possible, some people suggested ways to signal the extraterrestrials even before radio was discovered.

Carl Friedrich Gauss suggested that a giant triangle and three squares, the Pythagoras, could be drawn on the Siberian tundra. The outlines of the shapes would have been ten-mile wide strips of pine forest, the interiors could be rye or wheat.



The Pythagoras.

Joseph Johann Littrow proposed using the Sahara as a blackboard. Giant trenches several hundred yards wide could delineate twenty-mile wide shapes. Then the trenches would be filled with water, and then enough kerosene could be poured on top of the water to burn for six hours. Using this method, a different signal could be sent every night.

Meanwhile, other astronomers were looking for signs of life on other planets. In 1822, Franz von Gruithuisen thought he saw a giant city and evidence of agriculture on the moon, but astronomers using more powerful instruments refuted his claims. Gruithuisen also believed he saw evidence of life on Venus. Ashen light had been observed on Venus, and he postulated that it was caused by a great fire festival put on by the inhabitants to celebrate their new emperor. Later he revised his position, stating that the Venusians could be burning their rainforest to make more farmland.

By the late 1800s, the possibility of life on the moon was put to rest. Astronomers at that time believed in the Kant-Laplace hypothesis, which stated that the farthest planets from the sun are the oldest—therefore Mars was more likely to have advanced civilizations than Venus. It was evident that Venus was perpetually shrouded in clouds, so the Venusians probably wouldn't be very good astronomers. Subsequent investigations focused on contacting Martians. In 1877 Giovanni Schiaparelli announced he had discovered "canali" ("channels" in Italian, and mistranslated as "canals") on Mars—this was followed by thirty years of Mars enthusiasm.

The inventor Charles Cros was convinced that pinpoints of light observed on Mars and Venus were the lights of large cities. He spent years of his life trying to get funding for a giant mirror with which to signal the Martians. The mirror would be focused on the Martian desert, where the intense reflected sunlight could be used to burn figures into the Martian sand.

Inventor Nikola Tesla mentioned many times during his career that he thought his inventions such as his Tesla coil, used in the role of a "resonant receiver", could communicate with other planets and even observed repetitive signals of what he believed were Extraterrestrial radio communications coming from Venus or Mars in 1899. However, these "signals" turned out to be terrestrial radiation.

Around 1900, The Guzman Prize was created; the first person to establish interplanetary communication would be awarded 100,000 francs under one stipulation: Mars was excluded because Madame Guzman thought communicating with Mars would be too easy to deserve a prize.

When the Martian canals proved illusory, it seemed that humans were alone in the solar system.

Mathematical and scientific languages

Astraglossa

Published in 1953 by Lancelot Hogben describes a system for combining numbers and operators in a series of short and long pulses. In Hogben's system, short pulses represent numbers, while trains of long pulses represent symbols for addition, subtraction, etc.

Lincos (Lingua cosmica)

Lincos: Design of a Language for Cosmic Intercourse, published in 1960 by Hans Freudenthal, expands upon Astraglossa to create a general-purpose language derived from basic mathematics and logic symbols. A new generation Lincos has been developed since 2000 by Alexander Ollongren, as a part of the more general Astrolinguistics.

Carl Sagan

The science fiction novel *Contact* by Carl Sagan explored in some depth how a message might be constructed to allow communication with an alien civilization, using the prime numbers as a starting point, followed by various universal principles and facts of mathematics and science. Sagan also wrote a non-fiction book on the subject.

Jack McDevitt

In his science fiction novel *The Hercules Text*, Jack McDevitt describes an extraterrestrial message based on powers of 2 as a starting point.

A language based on the fundamental facts of science

Published in 1992 by Carl Devito and Richard Oehrle, is similar in syntax to Astraglossa and Lincos but builds its vocabulary around known physical properties.

Pictorial messages

Pictorial communication systems seek to describe fundamental mathematical or physical concepts via simplified diagrams sent as bitmaps. These messages assume that the recipient has similar visual capabilities (weak assumption) and can understand basic mathematics and geometry (strong assumption because both are prerequisites for building the optimal shape for a radio or optical telescope). A common critique of these systems is that they assume a shared understanding of special shapes, which may not be the case with a species with substantially different vision, and therefore a different way of interpreting visual information.

Pioneer probes

The two Pioneer plaques were launched on Pioneer 10 and Pioneer 11 in 1972 and 1973, depicting the location of the Earth in the galaxy and the solar system, and the form of the human body.

Voyager probes

Launched in 1977, the Voyager probes carried two golden records that were inscribed with diagrams depicting the human form, our solar system and its location. Also included were recordings of pictures and sounds from Earth.

The Arecibo message

The Arecibo message, transmitted in 1974, was a 1679 pixel image with 73 rows and 23 columns. It shows the numbers one through ten, the atomic numbers of hydrogen, carbon, nitrogen, oxygen, and phosphorus, the formulas for the sugars and bases in the nucleotides of DNA, the number of nucleotides in DNA, the double helix structure of DNA, a figure of a human being and its height, the population of Earth, a diagram of our solar system, and an image of the Arecibo telescope with its diameter.

Cosmic Call messages

The *Cosmic Call* messages consisted of a few digital sections - "Rosetta Stone", copy of Arecibo Message, Bilingual Image Glossary, the Braastad message, as well as text, audio, video and other image files submitted for transmission by everyday people around the world. The "Rosetta Stone" was composed by Stephane Dumas and Yvan Dutil and represents a multi-page bitmap that builds a vocabulary of symbols representing numbers and mathematical operations. The message proceeds from basic mathematics to progressively more complex concepts, including physical processes and objects (such as a hydrogen atom). The message is designed with noise resistant format and characters, which make it resistant to alteration by noise. These messages were transmitted in 1999 and 2003 from Evpatoria Planetary Radar under scientific guidance of Alexander L. Zaitsev. Richard Braastad coordinated the overall project.

Stars to which messages were sent, are the following:

Name	Designation HD	Constellation	Date sent	Arrival date	Message
16 Cyg A	HD 186408	Cygnus	May 24 , 1999	November 2069	Cosmic Call 1
15 Sge	HD 190406	Sagitta	June 30 , 1999	February 2057	Cosmic Call 1
	HD 178428	Sagitta	June 30 , 1999	October 2067	Cosmic Call 1
Gl 777	HD 190360	Cygnus	July 1 , 1999	April 2051	Cosmic Call 1
	Hip 4872	Cassiopeia	July 6 , 2003	April 2036	Cosmic Call 2
	HD 245409	Orion	July 6 , 2003	August 2040	Cosmic Call 2
55 Cnc	HD 75732	Cancer	July 6 , 2003	May 2044	Cosmic Call 2
	HD 10307	Andromeda	July 6 , 2003	September 2044	Cosmic Call 2

47 UMa HD 95128 Ursa Major July 6 , 2003 May 2049 Cosmic Call 2

Multi-modal messages

Teen-Age Message

The *Teen-Age Message*, composed by Russian scientists (Zaitsev, Gindilis, Pshenichner, Filippova) and teens, was transmitted from the 70-m dish of Yevpatoria Deep Space Center to six Sun-like stars on August 29 and September 3 and 4, 2001. The message consists of three parts:

Section 1 represents a coherent-sounding radio signal with slow Doppler wavelength tuning to imitate transmission from the Sun's center. This signal was transmitted in order to help extraterrestrials detect the TAM and diagnose the radio propagation effect of the interstellar medium.

Section 2 is **analog information** and represents musical melodies, performed on the Theremin. This electric musical instrument produces a quasi-monochromatic signal, which is easily detectable across interstellar distances. There were seven musical compositions in the 1st Theremin Concert for Aliens. It is important to understand that **analog** on-line transmission of the Theremin Concert in 14 minutes would take almost 50 hours in the case of transmission by the digital method.

Section 3 represents a well-known Arecibo-like binary digital information: the logotype of the TAM, bilingual Russian and English Greeting to Aliens, and Image Glossary.

Stars to which the message was sent are the following:

Name	HD designation	Constellation	Date sent	Arrival date
	197076	Delphinus	August 29 , 2001	February 2070
47 UMa	95128	Ursa Major	September 3 , 2001	July 2047
37 Gem	50692	Gemini	September 3 , 2001	December 2057
	126053	Virgo	September 3 , 2001	January 2059
	76151	Hydra	September 4 , 2001	May 2057
	193664	Draco	September 4 , 2001	January 2059

Cosmic Call 2 (Cosmic Call 2003) message

The Cosmic Call-2 message contained text, images, video, music, the Dutil/Dumas message, a copy of the 1974 Arecibo message, BIG = Bilingual Image Glossary, the AI program *Ella*, and the Braastad message.

Algorithmic messages

Algorithmic communication systems are a relatively new field within CETI. In these systems, which build upon early work on mathematical languages, the sender describes a small set of mathematics and logic symbols that form the basis for a rudimentary programming language that the recipient can run on a virtual machine. Algorithmic communication has a number of advantages over static pictorial and mathematical messages, including: localized communication (the recipient can probe and interact with the programs within a message, without transmitting a reply to the sender and then waiting years for a response), forward error correction (the message might contain algorithms that process data elsewhere in the message), and the ability to embed proxy agents within the message. In principle, a sophisticated program when run on a fast enough computing substrate, may exhibit complex behavior and perhaps intelligence.

CosmicOS

CosmicOS, designed by Paul Fitzpatrick at MIT, describes a virtual machine that is derived from lambda calculus.

Logic Gate Matrices

Logic Gate Matrices (a.k.a. LGM), developed by Brian McConnell, describes a universal virtual machine that is constructed by connecting coordinates in an n-dimensional space via mathematics and logic operations, for example: (1,0,0) <-- (OR (0,0,1) (0,0,2)). Using this method, one can describe an arbitrarily complex computing substrate as well as the instructions to be executed on it.

Natural Language Messages

This research focuses on the event that we receive a signal / message that is either not directed at us (eavesdropping) or one that is in its natural communicative form. To tackle this difficult but probable scenario, methods are being developed that will first detect if a signal has intelligent-like structure, categorize the type of structure detected and then decipher its content: from its physical level encoding and patterns to the parts-of-speech, which encode internal and external ontologies.

Primarily, this structure modeling focuses on the search for generic human and inter-species language universals to devise computational methods by which language can be discriminated from non-language and core structural syntactic elements of unknown languages can be detected. Aims of this research include: contributing to the understanding of language structure and the detection of intelligent language-like features in signals, to aid the search for extraterrestrial intelligence.

The problem goal is therefore to separate language from non-language without dialogue, and learn something about the structure of language in the passing. The language may not be human (animals, aliens, computers...), the perceptual space can be unknown, and we cannot assume human language structure but must begin somewhere. We need to

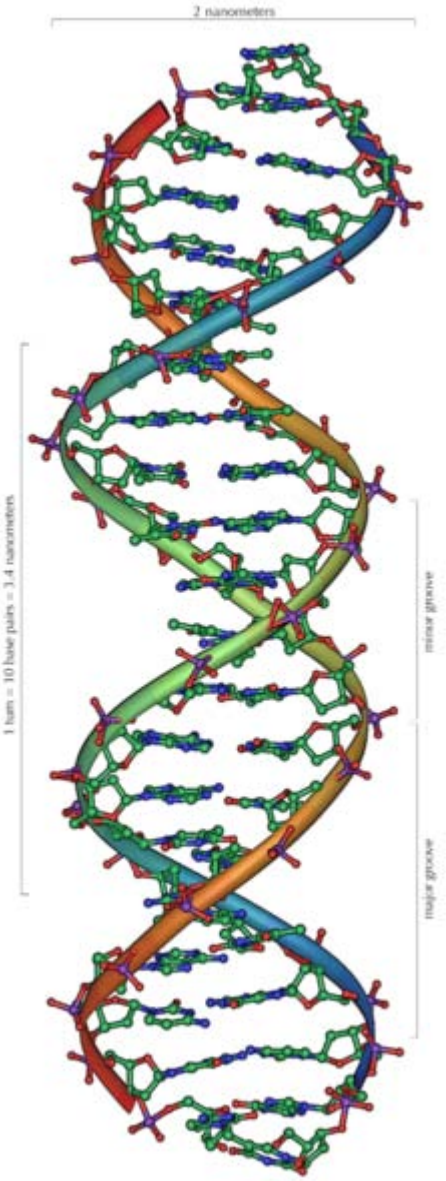
approach the language signal from a naive viewpoint, in effect, increasing our ignorance and assuming as little as possible.

CETI researchers

- Frank Drake (SETI Institute): SETI pioneer, composed the Arecibo message with Carl Sagan
- Dr John Elliott (SETI Research UK): research into developing strategies, which are based on receiving a 'natural' language message, that look at developing algorithms to detect if an ET signal has intelligent-like structure and if so, then how to decipher its content. Author of many papers in this area and a contributor to SETI's book on interstellar communication. Other contributions include message design and construction; member of: International Academy of Astronautics, SETI Permanent Study Group; International Task Group for the Post-detection identification of unknown radio signals.
- Laurence Doyle (SETI Institute): studies animal communication, and has developed statistical measures of complexity in animal utterances as well as human language.
- Stephane Dumas: developed *Cosmic Call* messages, as well as a general technique for generating 2-D symbols that remain recognizable even if corrupted by noise.
- Yvan Dutil: developed *Cosmic Call* messages with Stephane Dumas.
- Paul Fitzpatrick (MIT): developed *CosmicOS* system based on lambda calculus
- Brian McConnell: developed framework for algorithmic communication systems (ACETI) from 2000-2002.
- Marvin Minsky (MIT AI researcher): first proposed the idea of including algorithms within an interstellar message.
- Carl Sagan (deceased): co-authored the Arecibo message, and was heavily involved in SETI throughout his life.
- Douglas Vakoch (SETI Institute): studies CETI and has published numerous articles, as well as an upcoming book from MIT Press about interstellar communication.
- Alexander Zaitsev (IRE, Russia): composed *Teen Age Message* with Boris Pshenichner, Lev Gindilis, Lilia Filippova, et al., composed *Bilingual Image Glossary* for *Cosmic Call 2003 Message*, Scientific Manager of transmitting from Evpatoria Planetary Radar the Cosmic Call 1999, the Teen Age Message 2001, and the Cosmic Call 2003, Scientific consultant for A Message From Earth project.

Chapter- 5

Astrobiology

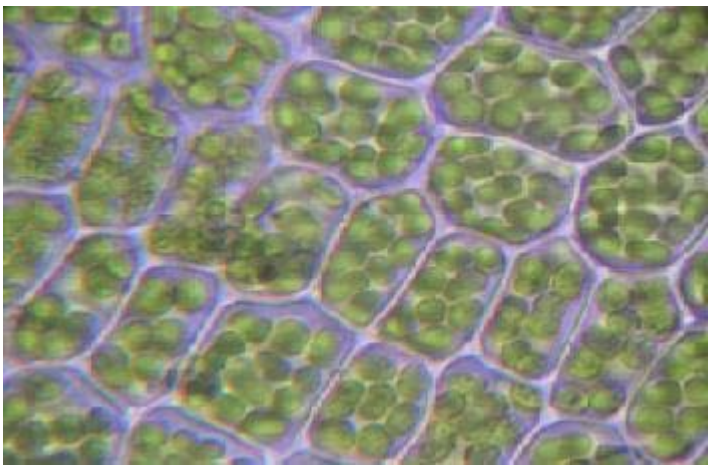


Nucleic acids may not be the only biomolecules in the Universe capable of coding for life.

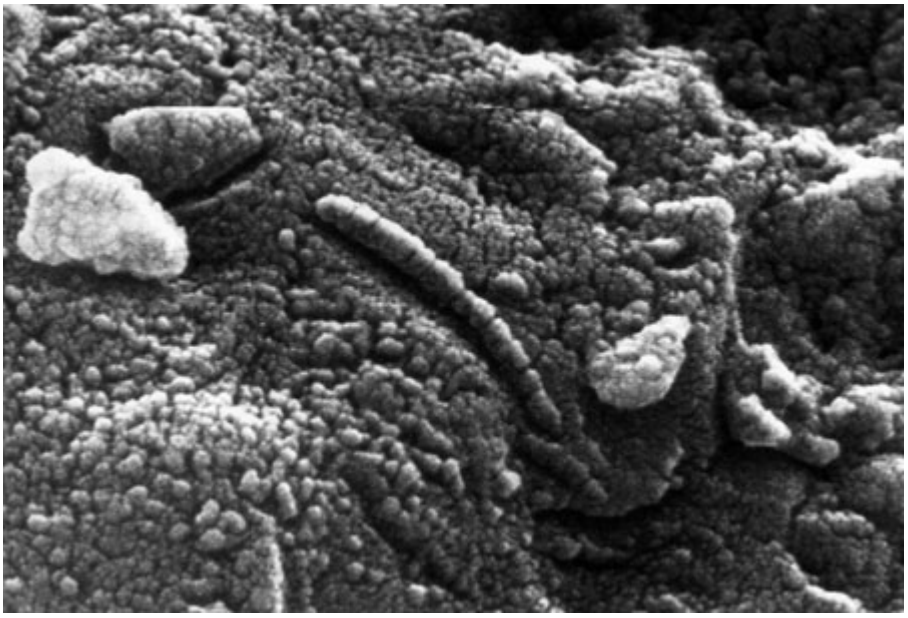
Astrobiology (or **exobiology**) is the study of the origin, evolution, distribution, and future of life in the universe. Earth is the only place in the universe known to harbour life. However, advancements in the fields of astrobiology, observational astronomy and discovery of large varieties of extremophiles with extraordinary capability to thrive in the harshest environments on Earth, have led to speculation that life may possibly be thriving on many of the extraterrestrial bodies in the universe. This interdisciplinary field encompasses the search for habitable environments in our Solar System and habitable planets outside our Solar System, the search for evidence of prebiotic chemistry, laboratory and field research into the origins and early evolution of life on Earth, and studies of the potential for life to adapt to challenges on Earth and in outer space.

Astrobiology makes use of physics, chemistry, astronomy, biology, molecular biology, ecology, planetary science, geography and geology to investigate the possibility of life on other worlds and help recognize biospheres that might be different from the biosphere on Earth. Astrobiology concerns itself with an interpretation of existing scientific data; given more detailed and reliable data from other parts of the Universe, the roots of astrobiology itself—physics, chemistry, and biology—may have their theoretical bases challenged. Although speculation is entertained to give context, astrobiology concerns itself primarily with hypotheses that fit firmly into existing scientific theories.

Overview



It is not known whether life elsewhere in the Universe would utilize cell structures like those found on Earth. (Chloroplasts within plant cells shown here.)



The Martian meteorite ALH84001 shows microscopic formations that may have been created by life.

Astrobiology is etymologically derived from the Greek ἄστρον, *astron*, "constellation, star"; βίος, *bios*, "life"; and -λογία, *-logia*, *study*. While it is an emerging and developing field, the question of whether life exists elsewhere in the universe is a verifiable hypothesis and thus a valid line of scientific inquiry. Though once considered outside the mainstream of scientific inquiry, astrobiology has become a formalized field of study. Planetary scientist David Grinspoon calls astrobiology a field of natural philosophy, grounding speculation on the unknown, in known scientific theory. NASA's interest in exobiology first began with the development of the U.S. Space Program. In 1959, NASA funded its first exobiology project, and in 1960, NASA founded an Exobiology Program; Exobiology research is now one of four elements of NASA's current Astrobiology Program. In 1971, NASA funded the Search for Extra-Terrestrial Intelligence (SETI) to search radio frequencies of the electromagnetic spectrum for signals being transmitted by extraterrestrial life outside the Solar System. NASA's Viking missions to Mars, launched in 1976, included three biology experiments designed to look for possible signs of life. The Mars Pathfinder lander in 1997 carried a scientific payload intended for exopaleontology in the hopes of finding microbial fossils entombed in the rocks.

In the 21st century, astrobiology is a focus of a growing number of NASA and European Space Agency Solar System exploration missions. The first European workshop on astrobiology took place in May 2001 in Italy, and the outcome was the Aurora programme. Currently, NASA hosts the NASA Astrobiology Institute and a growing number of universities in the United States (e.g., University of Arizona, Penn State University, Montana State University and University of Washington), Britain (e.g., The University of Glamorgan), Canada, Ireland, and Australia (e.g., The University of New South Wales) now offer graduate degree programs in astrobiology.

A particular focus of current astrobiology research is the search for life on Mars due to its proximity to Earth and geological history. There is a growing body of evidence to suggest that Mars has previously had a considerable amount of water on its surface, water being considered an essential precursor to the development of carbon-based life.

Missions specifically designed to search for life include the Viking program and Beagle 2 probes, both directed to Mars. The Viking results were inconclusive, and Beagle 2 failed to transmit from the surface and is assumed to have crashed. A future mission with a strong astrobiology role would have been the Jupiter Icy Moons Orbiter, designed to study the frozen moons of Jupiter—some of which may have liquid water—had it not been cancelled. Recently, the Phoenix lander probed the environment for past and present planetary habitability of microbial life on Mars, and to research the history of water there.

In 2011, NASA plans to launch the Mars Science Laboratory rover which will continue the search for past or present life on Mars using a variety of scientific instruments. The European Space Agency has been developing the ExoMars astrobiology rover, which is to be launched in 2018.

The International Astronomical Union regularly organizes major international conferences through its Commission 51: Bioastronomy. Commission 51 - Bioastronomy: Search for Extraterrestrial Life was established by the IAU in 1982 and is now hosted by the Institute of Astronomy at the University of Hawai'i.

Methodology

Narrowing the task

When looking for life on other planets, some simplifying assumptions are useful to reduce the size of the task of the astrobiologist. One is to assume that the vast majority of life forms in our galaxy are based on carbon chemistries, as are all life forms on Earth. While it is possible that non-carbon-based life forms exist, carbon is well known for the unusually wide variety of molecules that can be formed around it.

The presence of liquid water is a useful assumption, as it is a common molecule and provides an excellent environment for the formation of complicated carbon-based molecules that could eventually lead to the emergence of life. Some researchers posit environments of ammonia, or more likely, water-ammonia mixtures. These environments are considered suitable for carbon or noncarbon-based life, while opening more temperature ranges (and thus worlds) for life.

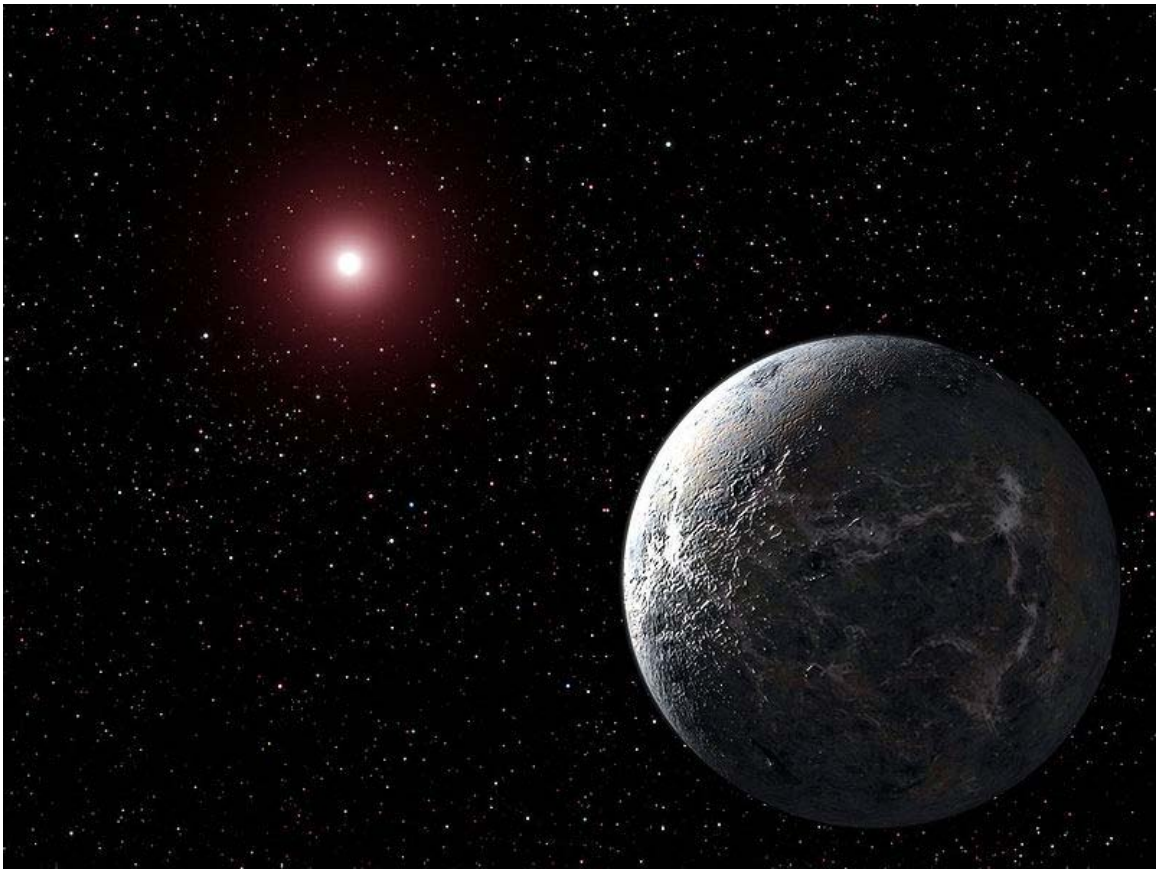
A third assumption is to focus on sun-like stars. This comes from the idea of planetary habitability. Very big stars have relatively short lifetimes, meaning that life would not likely have time to evolve on planets orbiting them. Very small stars provide so little heat and warmth that only planets in very close orbits around them would not be frozen solid, and in such close orbits these planets would be tidally "locked" to the star. Without a thick atmosphere, one side of the planet would be perpetually baked and the other

perpetually frozen. In 2005, the question was brought back to the attention of the scientific community, as the long lifetimes of red dwarfs could allow some biology on planets with thick atmospheres. This is significant, as red dwarfs are extremely common.

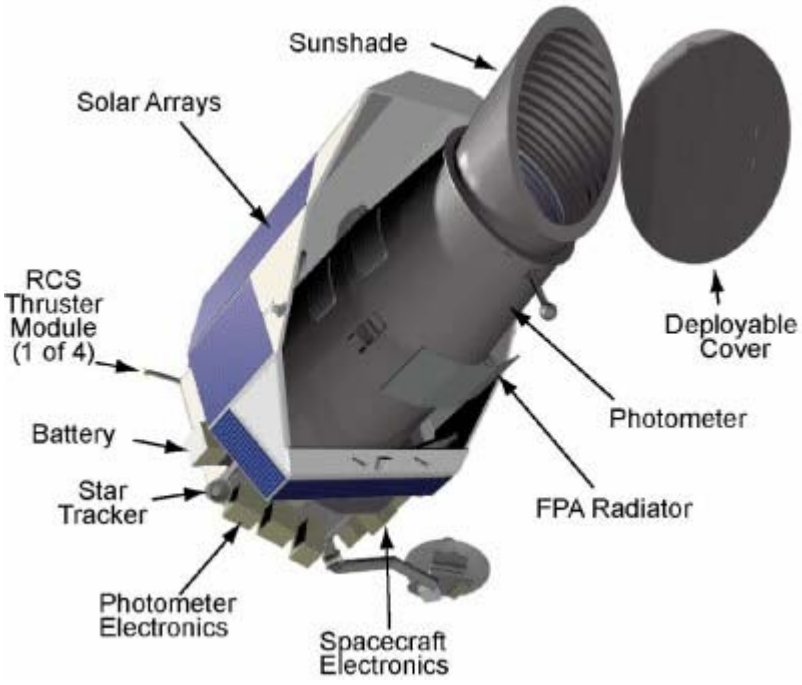
It is estimated that 10% of the stars in our galaxy are sun-like; There are about a thousand such stars within 100 light-years of our Sun. These stars would be useful primary targets for interstellar listening. Since Earth is the only planet known to harbor life, there is no evident way to know if any of the simplifying assumptions are correct.

Elements of astrobiology

Astronomy



Artist's impression of the extrasolar planet OGLE-2005-BLG-390Lb orbiting its star 20,000 light-years from Earth; this planet was discovered with gravitational microlensing.



The NASA Kepler mission, successfully launched in March 2009, searches for extrasolar planets

Most astronomy-related astrobiological research falls into the category of extrasolar planet (exoplanet) detection, the hypothesis being that if life arose on Earth, then it could also arise on other planets with similar characteristics. To that end, a number of instruments designed to detect Earth-like exoplanets are under development, most notably NASA's Terrestrial Planet Finder (TPF) and ESA's Darwin programs. Additionally, NASA has launched the Kepler mission in March 2009, and the French Space Agency has launched the COROT space mission in 2006. There are also several less ambitious ground-based efforts underway.

The goal of these missions is not only to detect Earth-sized planets, but also to directly detect light from the planet so that it may be studied spectroscopically. By examining planetary spectra, it would be possible to determine the basic composition of an extrasolar planet's atmosphere and/or surface; given this knowledge, it may be possible to assess the likelihood of life being found on that planet. A NASA research group, the Virtual Planet Laboratory, is using computer modeling to generate a wide variety of virtual planets to see what they would look like if viewed by TPF or Darwin. It is hoped that once these missions come online, their spectra can be cross-checked with these virtual planetary spectra for features that might indicate the presence of life. The photometry temporal variability of extrasolar planets may also provide clues to their surface and atmospheric properties.

An estimate for the number of planets with *intelligent* extraterrestrial life can be gleaned from the Drake equation, essentially an equation expressing the probability of intelligent life as the product of factors such as the fraction of planets that might be habitable and

the fraction of planets on which life might arise:

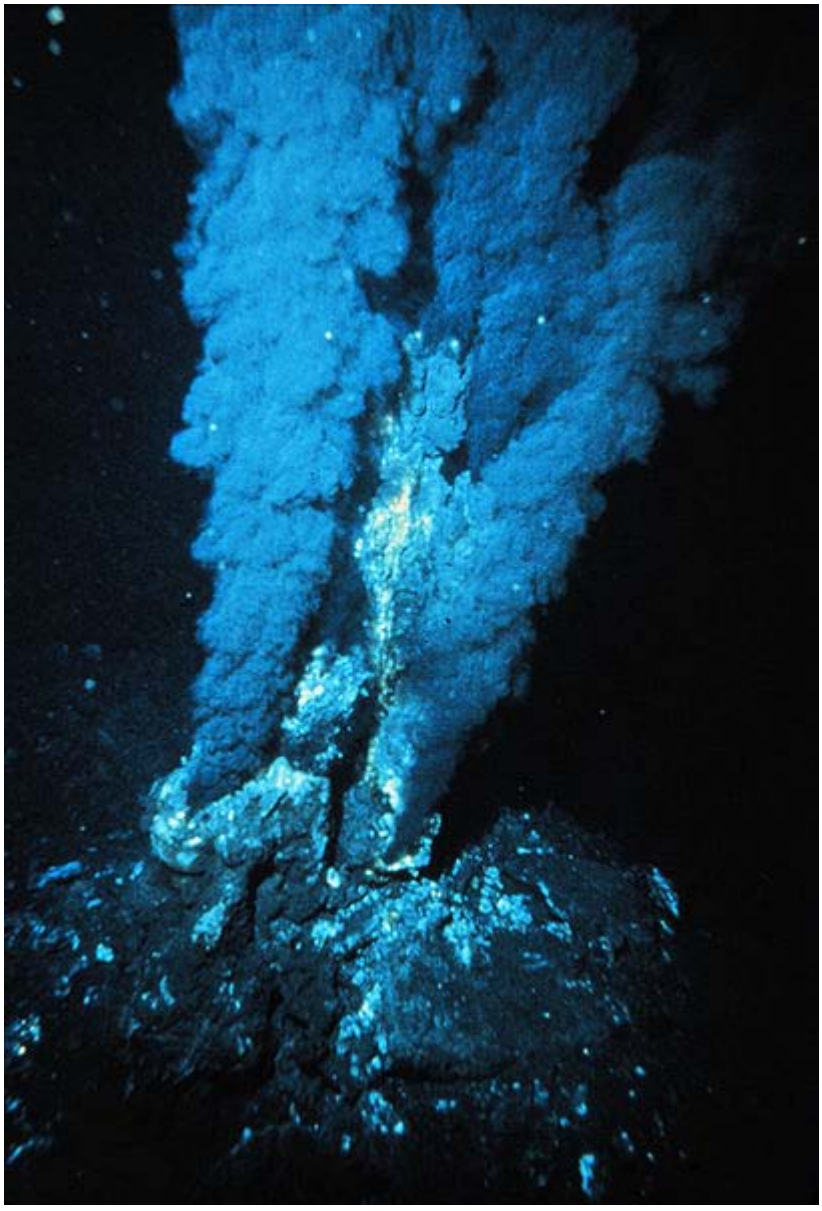
$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

where, **N** = The number of communicative civilizations, **R*** = The rate of formation of suitable stars (stars such as our Sun), **fp** = The fraction of those stars with planets. (Current evidence indicates that planetary systems may be common for stars like the Sun), **ne** = The number of Earth-like worlds per planetary system, **fl** = The fraction of those Earth-like planets where life actually develops, **fi** = The fraction of life sites where intelligence develops, **fc** = The fraction of communicative planets (those on which electromagnetic communications technology develops), **L** = The "lifetime" of communicating civilizations.

However, whilst the rationale behind the equation is sound, it is unlikely that the equation will be constrained to reasonable error limits any time soon. The first term, Number of Stars, is generally constrained within a few orders of magnitude. The second and third terms, Stars with Planets and Planets with Habitable Conditions, are being evaluated for the sun's neighborhood. Another associated topic is the Fermi paradox, which suggests that if intelligent life is common in the Universe, then there should be obvious signs of it. This is the purpose of projects like SETI, which tries to detect signs of radio transmissions from intelligent extraterrestrial civilizations.

Another active research area in astrobiology is Planetary system formation. It has been suggested that the peculiarities of our Solar System (for example, the presence of Jupiter as a protective shield) may have greatly increased the probability of intelligent life arising on our planet. No firm conclusions have been reached so far.

Biology



Hydrothermal vents are able to support extremophile bacteria on Earth and may also support life in other parts of the cosmos.

Extremophiles (organisms able to survive in extreme environments) are a core research element for astrobiologists. Such organisms include biota able to survive kilometers below the ocean's surface near hydrothermal vents and microbes that thrive in highly acidic environments.

Until the 1970s, life was believed to be entirely dependent on energy from the Sun. Plants on Earth's surface capture energy from sunlight to photosynthesize sugars from carbon dioxide and water, releasing oxygen in the process, and are then eaten by oxygen-

respiring animals, passing their energy up the food chain. Even life in the ocean depths, where sunlight cannot reach, was believed to obtain its nourishment either from consuming organic detritus rained down from the surface waters or from eating animals that did. A world's ability to support life was thought to depend on its access to sunlight. However, in 1977, during an exploratory dive to the Galapagos Rift in the deep-sea exploration submersible *Alvin*, scientists discovered colonies of giant tube worms, clams, crustaceans, mussels, and other assorted creatures clustered around undersea volcanic features known as black smokers. These creatures thrive despite having no access to sunlight, and it was soon discovered that they comprise an entirely independent food chain. Instead of plants, the basis for this food chain is a form of bacterium that derives its energy from oxidization of reactive chemicals, such as hydrogen or hydrogen sulfide, that bubble up from the Earth's interior. This chemosynthesis revolutionized the study of biology by revealing that life need not be sun-dependent; it only requires water and an energy gradient in order to exist. It is now known that extremophiles thrive in ice, boiling water, acid, the water core of nuclear reactors, salt crystals, toxic waste and in a range of other extreme habitats that were previously thought to be inhospitable for life. It opened up a new avenue in astrobiology by massively expanding the number of possible extraterrestrial habitats. Characterization of these organisms—their environments and their evolutionary pathways—is considered a crucial component to understanding how life might evolve elsewhere in the Universe. Some organisms able to withstand exposure to the vacuum and radiation of space include the lichen fungi Rhizocarpon geographicum and Xanthoria elegans, the bacterium *Bacillus safensis*, *Deinococcus radiodurans*, *Bacillus subtilis*, yeast *Saccharomyces cerevisiae*, seeds from *Arabidopsis thaliana* ('mouse-ear cress'), as well as the invertebrate animal Tardigrade.

On December 2, 2010 it was discovered that an extremophile bacterium (GFAJ-1) can be coaxed into partially substituting arsenic for phosphorus in some of its basic chemistry under laboratory conditions. It was announced that the bacterium can use the usually poisonous element arsenic in place of phosphorus. This discovery gives weight to the long-standing idea that life on other planets may have a radically different chemical makeup and may help in the search for alien life.

The origin of life, distinct from the evolution of life, is another ongoing field of research. Oparin and Haldane postulated that the conditions on the early Earth were conducive to the formation of organic compounds from inorganic elements and thus to the formation of many of the chemicals common to all forms of life we see today. The study of this process, known as prebiotic chemistry, has made some progress, but it is still unclear whether or not life could have formed in such a manner on Earth. The alternative theory of panspermia is that the first elements of life may have formed on another planet with even more favorable conditions (or even in interstellar space, asteroids, etc.) and then have been carried over to Earth by a variety of means. Jupiter's moon, Europa, is now considered to be the most likely location for extant extraterrestrial life in the Solar System.

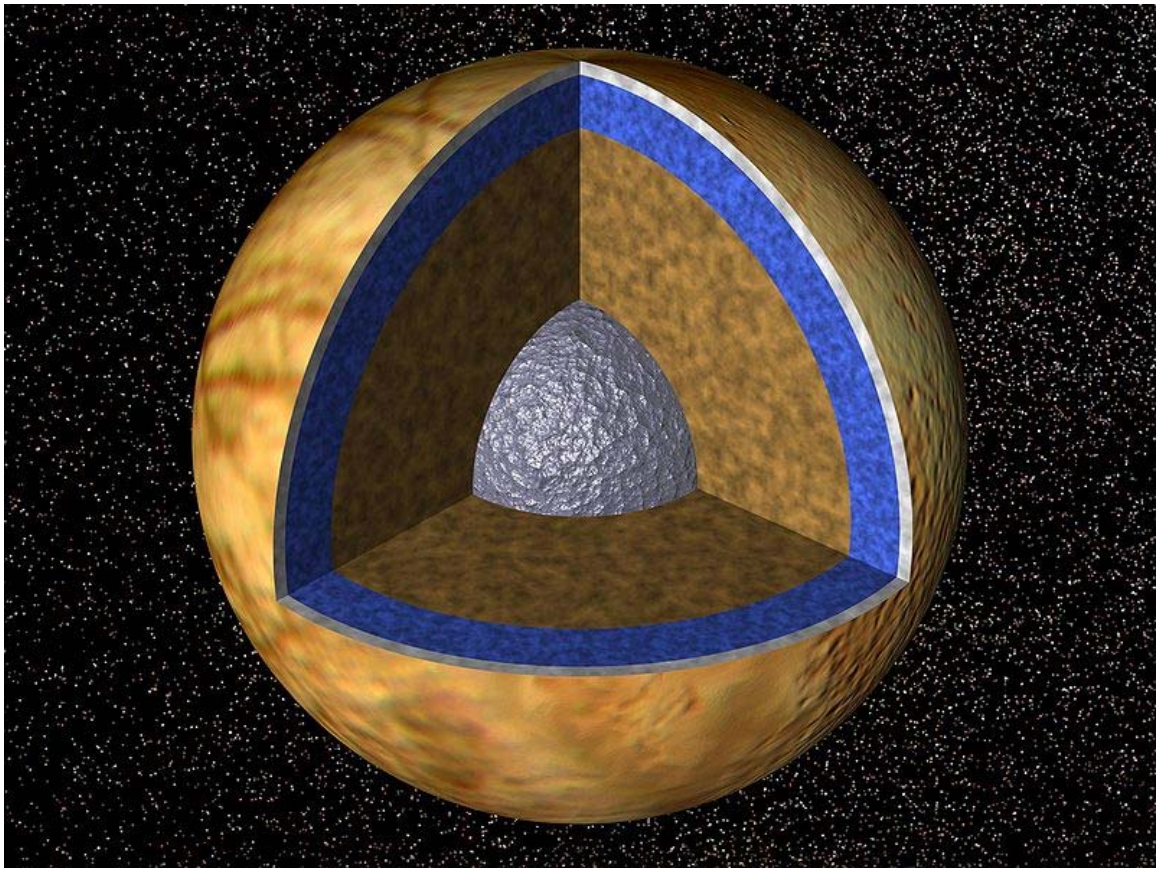
Astrogeology

Astrogeology is a planetary science discipline concerned with the geology of the celestial bodies such as the planets and their moons, asteroids, comets, and meteorites. The information gathered by this discipline allows the measure of a planet's or a natural satellite's potential to develop and sustain life, or planetary habitability.

An additional discipline of astrogeology is geochemistry, which involves study of the chemical composition of the Earth and other planets, chemical processes and reactions that govern the composition of rocks and soils, the cycles of matter and energy and their interaction with the hydrosphere and the atmosphere of the planet. Specializations include cosmochemistry, biochemistry and organic geochemistry.

The fossil record provides the oldest known evidence for life on Earth. By examining this evidence, paleontologists are able to understand better the types of organisms that arose on the early Earth. Some regions on Earth, such as the Pilbara in Western Australia and the McMurdo Dry Valleys of Antarctica, are also considered to be geological analogs to regions of Mars, and as such, might be able to provide clues on how to search for past life on Mars.

Life in the Solar System



Europa, due to the ocean that exists under its icy surface, might host some form of microbial life.

People have long speculated about the possibility of life in settings other than Earth, however, speculation on the nature of life elsewhere often has paid little heed to constraints imposed by the nature of biochemistry. The likelihood that life throughout the universe is probably carbon-based is encouraged by the fact that carbon is one of the most abundant of the higher elements. Only two of the natural atoms, carbon and silicon, are known to serve as the backbones of molecules sufficiently large to carry biological information. As the structural basis for life, one of carbon's important features is that unlike silicon it can readily engage in the formation of chemical bonds with many other atoms, thereby allowing for the chemical versatility required to conduct the reactions of biological metabolism and propagation. The various organic functional groups, composed of hydrogen, oxygen, nitrogen, phosphorus, sulfur, and a host of metals, such as iron, magnesium, and zinc, provide the enormous diversity of chemical reactions necessarily catalyzed by a living organism. Silicon, in contrast, interacts with only a few other atoms, and the large silicon molecules are monotonous compared with the combinatorial universe of organic macromolecules. Indeed, it seems likely that the basic building blocks of life anywhere will be similar to our own, in the generality if not in the detail. Although terrestrial life and life that might arise independently of Earth are expected to use many similar, if not identical, building blocks, they also are expected to have some biochemical qualities that are unique.

Thought on where in the Solar System life might occur was limited historically by the belief that life relies ultimately on light and warmth from the Sun and, therefore, is restricted to the surfaces of planets. The three most likely candidates for life in the Solar System are the planet Mars, the Jovian moon Europa, and Saturn's moon Titan. This speculation is primarily based on the fact that (in the cases of Mars and Europa) the planetary bodies may have liquid water, a molecule essential for life as we know it, for its use as a solvent in cells. Water on Mars is found in its polar ice caps, and newly carved gullies recently observed on Mars suggest that liquid water may exist, at least transiently, on the planet's surface, and possibly in subsurface environments such as hydrothermal springs as well. At the Martian low temperatures and low pressure, liquid water is likely to be highly saline. As for Europa, liquid water likely exists beneath the moon's icy outer crust. This water may be warmed to a liquid state by volcanic vents on the ocean floor (an especially intriguing theory considering the various types of extremophiles that live near Earth's volcanic vents), but the primary source of heat is probably tidal heating.

Another planetary body that could potentially sustain extraterrestrial life is Saturn's largest moon, Titan. Titan has been described as having conditions similar to those of early Earth. On its surface, scientists have discovered the first liquid lakes outside of Earth, but they seem to be composed of ethane and/or methane, not water. After Cassini data was studied, it was reported on March 2008 that Titan may also have an underground ocean composed of liquid water and ammonia. Additionally, Saturn's moon Enceladus may have an ocean below its icy surface.

Rare Earth hypothesis

This hypothesis states that based on astrobiological findings, multi-cellular life forms found on earth may actually be more of a rarity than scientists initially assumed. It provides a possible answer to the Fermi paradox which suggests, "If extraterrestrial aliens are common, why aren't they obvious?" It is apparently in opposition to the principle of mediocrity, assumed by famed astronomers Frank Drake, Carl Sagan, and others. The Principle of Mediocrity suggests that life on Earth is not exceptional, but rather that life is more than likely to be found on innumerable other worlds.

The anthropic principle states that fundamental laws of the universe work specifically in a way that life would be possible. The anthropic principle supports the Rare Earth Hypothesis by arguing the overall elements that are needed to support life on earth are so fine-tuned that it is nigh impossible for another just like it to exist by random chance (note that these terms are used by scientists in a different way from the vernacular conception of them). However, Stephen Jay Gould compared the claim that the universe is fine-tuned for the benefit of our kind of life to saying that sausages were made long and narrow so that they could fit into modern hot dog buns, or saying that ships had been invented to house barnacles.

Research

The systematic search for possible life outside of Earth is a valid multidisciplinary scientific endeavor. The University of Glamorgan, UK, started just such a degree in 2006, and the American government funds the NASA Astrobiology Institute. However, characterization of non-Earth life is unsettled; hypotheses and predictions as to its existence and origin vary widely, but at the present, the development of theories to inform and support the exploratory search for life may be considered astrobiology's most concrete practical application.

Biologist Jack Cohen and mathematician Ian Stewart, amongst others, consider **xenobiology** separate from astrobiology. Cohen and Stewart stipulate that astrobiology is the search for Earth-like life outside of our solar system and say that xenobiologists are concerned with the possibilities open to us once we consider that life need not be carbon-based or oxygen-breathing, so long as it has the defining characteristics of life.

Research outcomes

Asteroid(s) may have transported life to Earth.

As of 2010, no proof of extraterrestrial life has been identified. Examination of the ALH 84001 meteorite, which was recovered in Antarctica in 1984 and believed to have originated from Mars, is thought by David McKay, Chief Scientist for Astrobiology at NASA's Johnson Space Center, as well as other scientists, to contain microfossils of extraterrestrial origin; this interpretation is controversial.

Methane

In 2004, the spectral signature of methane was detected in the Martian atmosphere by both Earth-based telescopes as well as by the Mars Express probe. Because of solar radiation and cosmic radiation, methane is predicted to disappear from the Martian atmosphere within several years, so the gas must be actively replenished in order to maintain the present concentration. The Mars Science Laboratory rover will perform precision measurements of oxygen and carbon isotope ratios in carbon dioxide (CO_2) and methane (CH_4) in the atmosphere of Mars in order to distinguish between a geochemical and a biological origin.

Planetary systems

It is possible that some planets, like the gas giant Jupiter in our solar system, may have moons with solid surfaces or liquid oceans that are more hospitable. Most of the planets so far discovered outside our solar system are hot gas giants thought to be inhospitable to life, so it is not yet known whether our solar system, with a warm, rocky, metal-rich inner planet such as Earth, is of an aberrant composition. Improved detection methods and increased observing time will undoubtedly discover more planetary systems, and possibly some more like ours. For example, NASA's Kepler Mission seeks to discover Earth-sized planets around other stars by measuring minute changes in the star's light curve as the planet passes between the star and the spacecraft. Progress in infrared astronomy and submillimeter astronomy has revealed the constituents of other star systems. Infrared searches have detected belts of dust and asteroids around distant stars, underpinning the formation of planets.

Planetary habitability

Efforts to answer questions such as the abundance of potentially habitable planets in habitable zones and chemical precursors have had much success. Numerous extrasolar planets have been detected using the wobble method and transit method, showing that planets around other stars are more numerous than previously postulated. The first Earth-like extrasolar planet to be discovered within its star's habitable zone is Gliese 581 c, which was found using radial velocity.

Research into the environmental limits of life and the workings of extreme ecosystems is also ongoing, enabling researchers to predict what planetary environments might be most likely to harbor life. Missions such as the Phoenix lander, Mars Science Laboratory, ExoMars to Mars, the Cassini probe to Saturn's moon Titan, and the "Ice Clipper" mission to Jupiter's moon Europa hope to further explore the possibilities of life on other planets in our solar system.

Chapter- 6

Habitable Zone

In astronomy, the **habitable zone (HZ)** is the distance from a star where an Earth-like planet can maintain liquid water on its surface and Earth-like life. The habitable zone is the intersection of two regions that must both be favorable to life; one within a planetary system, and the other within a galaxy. Planets and moons in these regions are the likeliest candidates to be habitable and thus capable of bearing extraterrestrial life similar to our own. The concept generally does not include moons, because there is insufficient evidence and theory to speculate what moons might be habitable on account of their proximity to a planet.

The habitable zone is not to be confused with the planetary habitability. While planetary habitability deals solely with the planetary conditions required to maintain carbon-based life, the habitable zone deals with the stellar conditions required to maintain carbon-based life, and these two factors are not meant to be interchanged.

Life is most likely to form within the **circumstellar habitable zone** (**CHZ**) within a solar system, and the **galactic habitable zone** (**GHZ**) of the larger galaxy (though research on the latter point remains in its infancy). The HZ may also be referred to as the "life zone", "Comfort Zone", "Green Belt" or "Goldilocks Zone" (because it's neither too hot nor too cold, but "just right").

Circumstellar habitable zone

Within a planetary system, a planet must lie within the habitable zone in order to sustain liquid water on its surface. Beyond the outer edge, a planet will not receive enough solar radiation to make up for radiative losses, leaving water to freeze. A planet closer than the inner edge of this zone will absorb too much radiation, boiling away surface water. The circumstellar habitable zone (or **ecosphere**) is the spherical shell of space surrounding a star where such planets might exist. Liquid water is considered important because Carbon compounds dissolved in water form the basis of all Earthly life, so watery planets are good candidates to support similar carbon-based biochemistries. Even on a "dead" world, the presence of liquid water would greatly simplify the colonization of the planet.

For example, a star with 25% of the luminosity that the Sun has will have a CHZ centered at about 0.50 AU, while a star with twice the Sun's luminosity will have a CHZ centered

at about 1.4 AU. This is a consequence of the inverse square law of luminous intensity. The "center" of the HZ is defined as the distance that an exoplanet would have to be from its parent star in order to receive the right amount of energy from the star to maintain liquid water.

Gliese 581 g, currently believed to be the fourth planet of the red dwarf star Gliese 581 (approximately 20 light years distance from Earth), appears to be the best example which has been found so far of an extrasolar planet which orbits in the theoretical circumstellar habitable zone of space surrounding its star.

55 Cancri f, though a Jupiter like gas giant exoplanet, orbits and also resides within the yellow dwarf star companion of 55 Cancri binary star systems habitable zone. While conditions upon this massive and dense planet are not conducive to the formation of water or for that matter biological life as what is known, they potentiality exist for a system of satellite moons to be orbiting the planet 55 Cancri f and thus transiting through this biologically conducive zone for development.

GJ 1214 b, though just outside of the habitable zone, does provide indications of being an ocean planet, meaning it is believed to be an extrasolar planet of the superearth variety, surrounded by a deep liquid ocean of water, similar to some of the Jovian Moons of the Sun's solar system, only with much warmer temperatures than these ice covered water worlds.

HD 28185 b takes 1.04 years to orbit its parent star. Unlike most known long-period planets, the orbit of HD 28185 b has a low eccentricity, comparable to that of Mars in our solar system. The orbit lies entirely within its star's habitable zone. Since HD 28185 b orbits in its star's habitable zone, some have speculated on the possibility of life on worlds in the HD 28185 system. While it is unknown whether gas giants can support life, simulations of tidal interactions suggest that HD 28185 b could harbor Earth-mass satellites in orbit around it for many billions of years. Such moons, if they exist, may be able to provide a habitable environment, though it is unclear whether such satellites would form in the first place.

Habitable zone edge predictions for our solar system

In our own solar system, the CHZ is thought to extend from a distance of 0.725 to 3.0 astronomical units, based on various scientific models:

INNER edge	OUTER edge		Notes
0.725 AU	1.24 AU	Dole 1964	Used optically thin atmospheres and fixed albedos.
0.95 AU	1.01 AU	Hart et al. 1978, 1979	stars K0 or later cannot have HZs
0.95 AU	3.0 AU	Fogg 1992	Used Carbon cycles.

0.95 AU	1.37 AU	Kasting et al. 1993	
–	1%–2% farther out	Budyko 1969	... and Earth would have global glaciation.
–	1%–2% farther out	Sellers 1969	... and Earth would have global glaciation.
–	1%–2% farther out	North 1975	... and Earth would have global glaciation.
4%–7% closer	–	Rasool & DeBurgh 1970	... and oceans would never have condensed.
–	–	Schneider and Thompson 1980	disagreed with Hart.
–	–	Kasting 1991	
–	–	Kasting 1988	Water clouds can shrink HZ as they counter GHG effect with higher albedos.
–	–	Ramanathan and Collins 1991	GHG effect IR trapping is greater than water cloud albedo cooling, and Venus would have to have started "Dry."
–	–	Lovelock 1991	
–	–	Whitemire et al. 1991	

Galactic habitable zone

The location of a planetary system within a galaxy must also be favorable to the development of life, and this has led to the concept of a galactic habitable zone (GHZ), although the concept has recently been challenged.

To harbor life, a system must be close enough to the galactic center that a sufficiently high level of heavy elements exist to favor the formation of rocky, or terrestrial, planets, which are needed to support life. Heavier elements also need to be present, as they are the basis of the complex molecules of life. While any specific example of a heavier element may not be necessary for all life, heavier elements in general become increasingly necessary for complex life on Earth (both as complex molecules and as sources of energy). It is assumed they would also be necessary for simpler and especially more complex life on other planets.

On the other hand, the planetary system must be far enough from the galactic center that it would not be affected by dangerous high-frequency radiation, which would damage any carbon-based life. Also, most of the stars in the galactic center are old, unstable, dying stars, meaning that few or no stars form in the galactic center. Because terrestrial

planets form from the same types of nebulae as stars, it can be reasoned that if stars cannot form in the galactic center, then terrestrial planets cannot, either.

In our galaxy (the Milky Way), the GHZ is currently believed to be a slowly expanding region approximately 25,000 light years (8 kiloparsecs) from the galactic core and some 6,000 light years in width (2 kiloparsecs), containing stars roughly 4 billion to 8 billion years old. Other galaxies differ in their compositions, and may have a larger or smaller GHZ – or none at all (*see: elliptical galaxy*).

Goldilocks zone

"This porridge is too hot," Goldilocks exclaimed.
So she tasted the porridge from the second bowl.
"This porridge is too cold."
So she tasted the last bowl of porridge.
"Ahhh, this porridge is just right!" she said happily.
And she ate it all up.

Goldilocks and the three bears

The term "Goldilocks zone" is often used in popular writing as a nickname for the Habitable zone. The term comes from the children's fairy tale Goldilocks and the Three Bears, and is used to describe conditions that are not too hot nor too cold for life as we know it.

Criticism

- The concept of a habitable zone is criticized by Ian Stewart and Jack Cohen in their book *Evolving the Alien*, for two reasons: the first is that the hypothesis assumes alien life has the same requirements as terrestrial life; the second is that, even assuming this, other circumstances may result in suitable planets outside the "habitable zone". For instance, Jupiter's moon Europa is thought to have a subsurface ocean with an environment similar to the deep oceans of Earth. The existence of extremophiles (such as the tardigrades) on Earth makes life on Europa seem more plausible, despite the fact that Europa is not in the presumed CHZ. Astronomer Carl Sagan believed that life was also possible on the gas giants, such as Jupiter itself. A discovery of any form of life in such an environment would expose these hypothetical restrictions as too conservative. Life can evolve to tolerate extreme conditions when the relevant selection pressures dictate, and thus it is not necessary for them to be "just right".

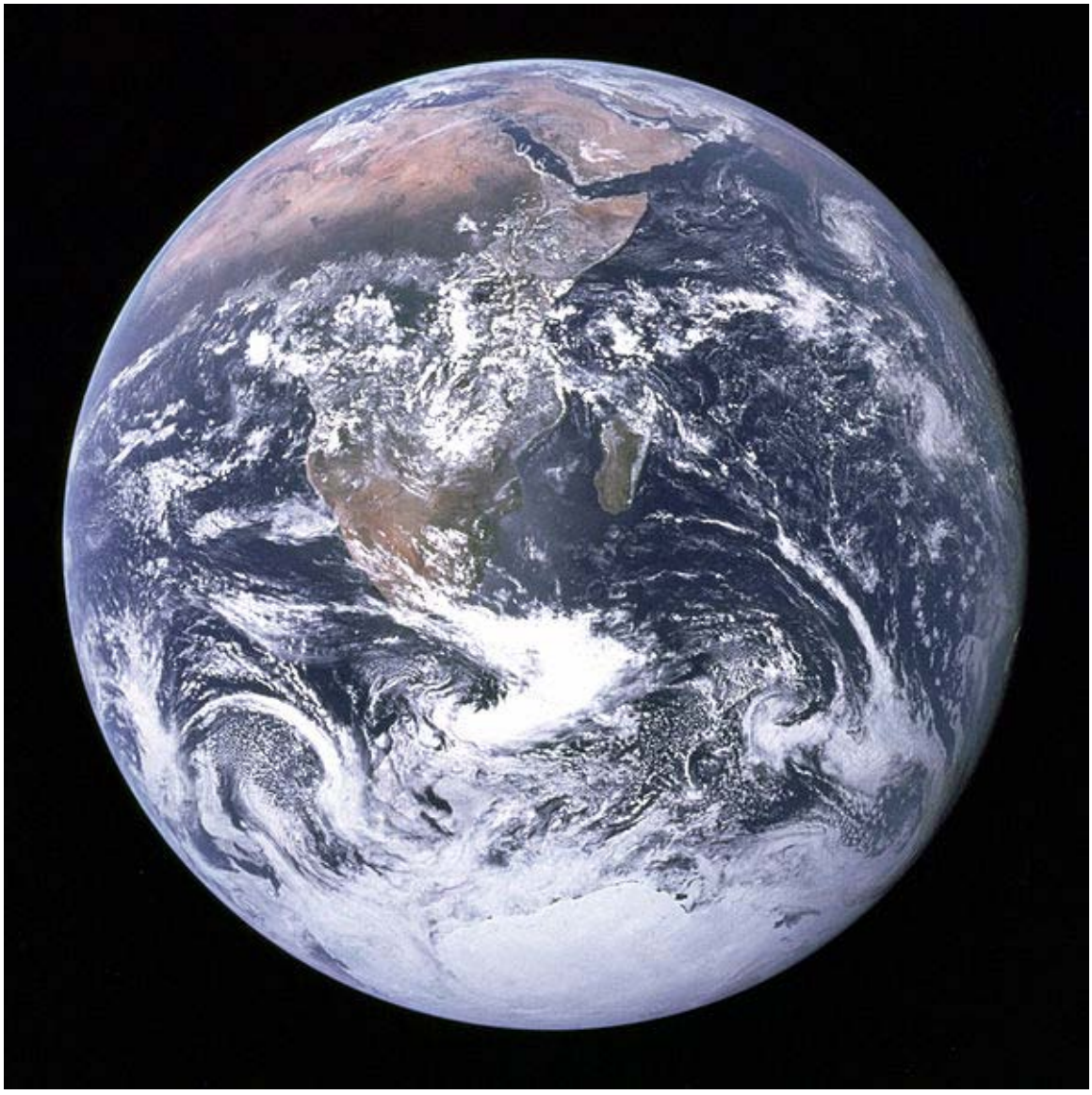
- Differing levels of volcanic activity, lunar effects, planetary mass, and even radioactive decay may affect the radiation and heat levels acting on a planet to modify conditions supporting life. And while it is likely that Earth life could adapt to an environment like Europa's, it is far less likely for life to develop there in the first place, or to move there and adapt without advanced technology. Therefore, a

planet that has moved away from a habitable zone is more likely to have life than one that has moved into it.

- Scientists describe extensive computer simulations in the *Astrophysical Journal* that show that, at least in galaxies similar to our own Milky Way, stars such as the sun can migrate great distances, thus challenging the notion that parts of these galaxies are more conducive to supporting life than other areas.

Chapter- 7

Planetary Habitability



Understanding planetary habitability is partly an extrapolation of the Earth's conditions, as it is the only planet currently known to support life

Planetary habitability is the measure of a planet's or a natural satellite's potential to sustain life. Life may develop directly on a planet or satellite or be transferred to it from another body, a theoretical process known as panspermia. As the existence of life beyond Earth is currently uncertain, planetary habitability is largely an extrapolation of conditions on Earth and the characteristics of the Sun and solar system which appear favorable to life's flourishing—in particular those factors that have sustained complex, multicellular organisms and not just simpler, unicellular creatures. Research and theory in this regard is a component of planetary science and the emerging discipline of astrobiology.

An absolute requirement for life is an energy source, and the notion of planetary habitability implies that many other geophysical, geochemical, and astrophysical criteria must be met before an astronomical body can support life. In its astrobiology roadmap, NASA has defined the principal habitability criteria as "extended regions of liquid water, conditions favorable for the assembly of complex organic molecules, and energy sources to sustain metabolism."

In determining the habitability potential of a body, studies focus on its bulk composition, orbital properties, atmosphere, and potential chemical interactions. Stellar characteristics of importance include mass and luminosity, stable variability, and high metallicity. Rocky, terrestrial-type planets and moons with the potential for Earth-like chemistry are a primary focus of astrobiological research, although more speculative habitability theories occasionally examine alternative biochemistries and other types of astronomical bodies.

The idea that planets beyond Earth might host life is an ancient one, though historically it was framed by philosophy as much as physical science.[a] The late 20th century saw two breakthroughs in the field. The observation and robotic spacecraft exploration of other planets and moons within the solar system has provided critical information on defining habitability criteria and allowed for substantial geophysical comparisons between the Earth and other bodies. The discovery of extrasolar planets, beginning in the early 1990s and accelerating thereafter, has provided further information for the study of possible extraterrestrial life. Most importantly, it confirmed that the Sun is not unique among stars in hosting planets and expanded the habitability research horizon beyond our own solar system.

Suitable star systems

An understanding of planetary habitability begins with stars. While bodies that are generally Earth-like may be plentiful, it is just as important that their larger system be agreeable to life. Under the auspices of SETI's Project Phoenix, scientists Margaret Turnbull and Jill Tarter developed the "HabCat" (or Catalogue of Habitable Stellar Systems) in 2002. The catalogue was formed by winnowing the nearly 120,000 stars of the larger Hipparcos Catalogue into a core group of 17,000 "HabStars," and the selection criteria that were used provide a good starting point for understanding which astrophysical factors are necessary to habitable planets.

Spectral class

The spectral class of a star indicates its photospheric temperature, which (for main-sequence stars) correlates to overall mass. The appropriate spectral range for "HabStars" is presently considered to be "early F" or "G", to "mid-K". This corresponds to temperatures of a little more than 7,000 K down to a little more than 4,000 K; the Sun, a G2 star, is well within these bounds. "Middle-class" stars of this sort have a number of characteristics considered important to planetary habitability:

- They live at least a few billion years, allowing life a chance to evolve. More luminous main-sequence stars of the "O," "B," and "A" classes usually live less than a billion years and in exceptional cases less than 10 million. [b]
- They emit enough high-frequency ultraviolet radiation to trigger important atmospheric dynamics such as ozone formation, but not so much that ionisation destroys incipient life.
- Liquid water may exist on the surface of planets orbiting them at a distance that does not induce tidal lock. K Spectrum stars may be able to support life for long periods, far longer than our sun.

This spectral range probably accounts for between 5% and 10% of stars in the local Milky Way galaxy. Whether fainter late K and M class red dwarf stars are also suitable hosts for habitable planets is perhaps the most important open question in the entire field of planetary habitability given their ubiquity. Gliese 581 c, a "super-Earth," has been found orbiting in the habitable zone of a red dwarf and may possess liquid water. Alternately, a greenhouse effect may render it too hot to support life, while its neighbor, Gliese 581 d, may in fact be a more likely candidate for habitability. In September 2010, the discovery was announced of another planet in an orbit between these two planets. Gliese 581 g is located in the habitable zone of the Gliese 581 system and is an even more suitable canditate for supporting life.

A stable habitable zone

The habitable zone (HZ) is a theoretical shell surrounding a star in which any planet present would have liquid water on its surface. After an energy source, liquid water is considered the most important ingredient for life, considering how integral it is to all life-systems on Earth. This may reflect the bias of humanity's water-dependent biology, however, and if life is discovered in the absence of water (for example, in a liquid-ammonia solution), the notion of an HZ may have to be greatly expanded or else discarded altogether as too restricting.[c]

A "stable" HZ denotes two factors. First, the range of an HZ should not vary greatly over time. All stars increase in luminosity as they age and a given HZ naturally migrates outwards, but if this happens too quickly (for example, with a super-massive star), planets may only have a brief window inside the HZ and a correspondingly weaker chance to develop life. Calculating an HZ range and its long-term movement is never straightforward, given that negative feedback loops such as the carbon cycle will tend to

offset the increases in luminosity. Assumptions made about atmospheric conditions and geology thus have as great an impact on a putative HZ range as does Solar evolution; the proposed parameters of the Sun's HZ, for example, have fluctuated greatly.

Secondly, no large-mass body such as a gas giant should be present in or relatively close to the HZ, thus disrupting the formation of Earth-like bodies. The mass of the asteroid belt, for example, appears to have been unable to accrete into a planet due to orbital resonances with Jupiter; if the giant had appeared in the region that is now between the orbits of Venus and Mars, Earth would almost certainly not have developed its present form. This is somewhat ameliorated by suggestions that a gas giant inside the HZ might have habitable moons under the right conditions.

The Solar System follows an inner-terrestrial planet, outer-gas giant pattern, but discoveries of extrasolar planets suggest this may not be common to other stellar systems: numerous Jupiter-sized bodies have been found in close orbit about their primary, disrupting potential HZs. However, present data for extrasolar planets is likely to be skewed towards these types (large planets in close orbits) because they are far easier to identify; thus, it remains to be seen which type of stellar system is the norm, or indeed if there is one.

Low stellar variation

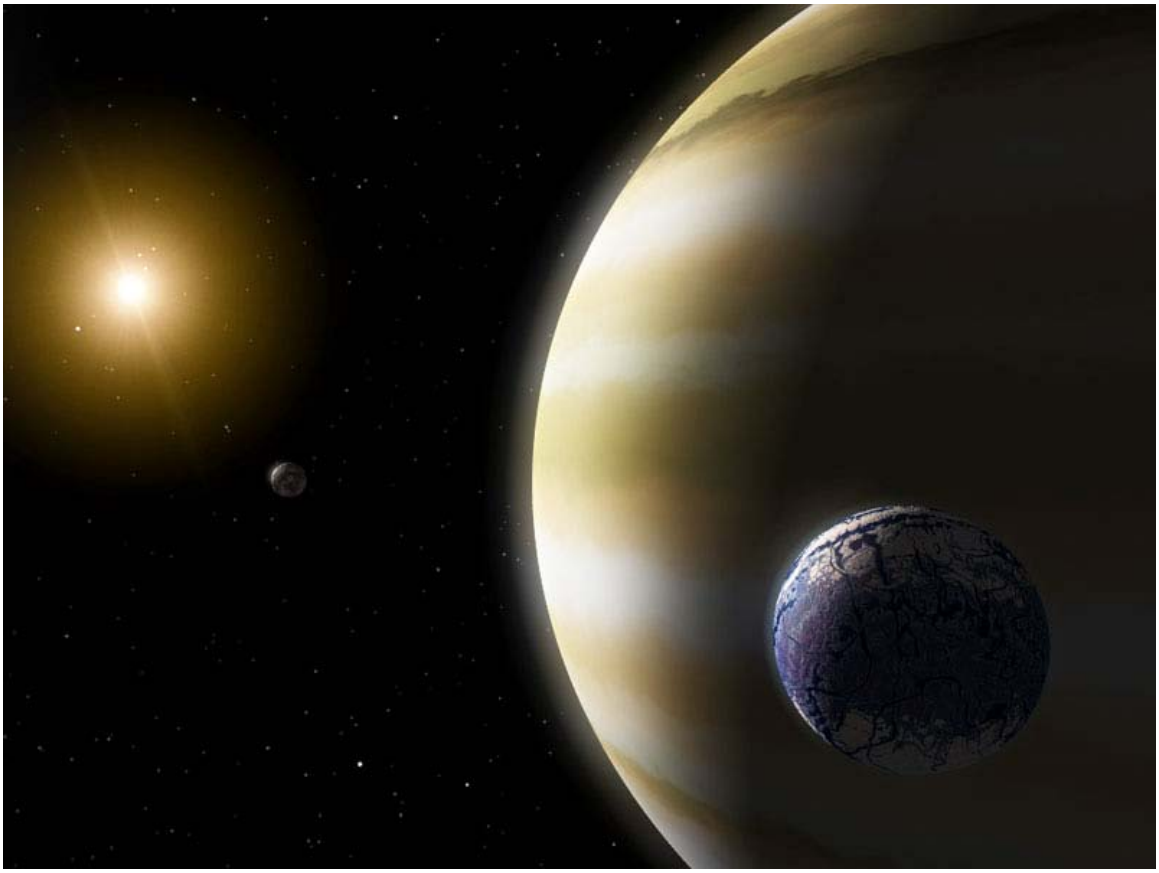
Changes in luminosity are common to all stars, but the severity of such fluctuations covers a broad range. Most stars are relatively stable, but a significant minority of variable stars often experience sudden and intense increases in luminosity and consequently the amount of energy radiated toward bodies in orbit. These are considered poor candidates for hosting life-bearing planets as their unpredictability and energy output changes would negatively impact organisms. Particularly, living things adapted to a specific temperature range would probably be unable to survive too great a temperature deviation. Further, upswings in luminosity are generally accompanied by massive doses of gamma ray and X-ray radiation which might prove lethal. Atmospheres do mitigate such effects, but atmosphere retention might not occur on planets orbiting variables, because the high-frequency energy buffeting these bodies would continually strip them of their protective covering.

The Sun, as in much else, is benign in terms of this danger: the variation between solar max and minimum is roughly 0.1% over its 11-year solar cycle. There is strong (though not undisputed) evidence that even minor changes in the Sun's luminosity have had significant effects on the Earth's climate well within the historical era; the Little Ice Age of the mid-second millennium, for instance, may have been caused by a relatively long-term decline in the Sun's luminosity. Thus, a star does not have to be a true variable for differences in luminosity to affect habitability. Of known "solar analogs," the one that most closely resembles the Sun is considered to be 18 Scorpii; unfortunately for the prospects of life existing in its proximity, the only significant difference between the two bodies is the amplitude of the solar cycle, which appears to be much greater for 18 Scorpii.

High metallicity

While the bulk of material in any star is hydrogen and helium, there is a great variation in the amount of heavier elements (metals) stars contain. A high proportion of metals in a star correlates to the amount of heavy material initially available in protoplanetary disks. A low amount of metal significantly decreases the probability that planets will have formed around that star, under the solar nebula theory of planetary systems formation. Any planets that did form around a metal-poor star would probably be low in mass, and thus unfavorable for life. Spectroscopic studies of systems where exoplanets have been found to date confirm the relationship between high metal content and planet formation: "stars with planets, or at least with planets similar to the ones we are finding today, are clearly more metal rich than stars without planetary companions." High metallicity also places a requirement for youth on hab-stars: stars formed early in the universe's history have low metal content and a correspondingly lesser likelihood of having planetary companions.

Planetary characteristics



The moons of some gas giants could potentially be habitable.

The chief assumption about habitable planets is that they are terrestrial. Such planets, roughly within one order of magnitude of Earth mass, are primarily composed of silicate rocks and have not accreted the gaseous outer layers of hydrogen and helium found on gas giants. That life could evolve in the cloud tops of giant planets has not been decisively ruled out,[d] though it is considered unlikely given that they have no surface and their gravity is enormous. The natural satellites of giant planets, meanwhile, remain perfectly valid candidates for hosting life.

In analyzing which environments are likely to support life, a distinction is usually made between simple, unicellular organisms such as bacteria and archaea and complex metazoans (animals). Unicellularity necessarily precedes multicellularity in any hypothetical tree of life and where single-celled organisms do emerge there is no assurance that this will lead to greater complexity.[e] The planetary characteristics listed below are considered crucial for life generally, but in every case habitability impediments should be considered greater for multicellular organisms such as plants and animals versus unicellular life.

Mass

Mars, with its rarefied atmosphere, is colder than the Earth would be, if it were at a similar distance from the Sun

Low-mass planets are poor candidates for life for two reasons. First, their lesser gravity makes atmosphere retention difficult. Constituent molecules are more likely to reach escape velocity and be lost to space when buffeted by solar wind or stirred by collision. Planets without a thick atmosphere lack the matter necessary for primal biochemistry, have little insulation and poor heat transfer across their surfaces (for example, Mars, with its thin atmosphere, is colder than the Earth would be if it were at a similar distance from the sun), and provide less protection against meteoroids and high-frequency radiation. Further, where an atmosphere is less than 0.006 Earth atmospheres, water cannot exist in liquid form as the required atmospheric pressure, 4.56 mm Hg (608 Pa) (0.18 inch Hg),

does not occur. The temperature range at which water is liquid is smaller at low pressures generally.

Secondly, smaller planets have smaller diameters and thus higher surface-to-volume ratios than their larger cousins. Such bodies tend to lose the energy left over from their formation quickly and end up geologically dead, lacking the volcanoes, earthquakes and tectonic activity which supply the surface with life-sustaining material and the atmosphere with temperature moderators like carbon dioxide. Plate tectonics appear particularly crucial, at least on Earth: not only does the process recycle important chemicals and minerals, it also fosters bio-diversity through continent creation and increased environmental complexity and helps create the convective cells necessary to generate Earth's magnetic field.

"Low mass" is partly a relative label; the Earth is considered low mass when compared to the Solar System's gas giants, but it is the largest, by diameter and mass, and densest of all terrestrial bodies.[f] It is large enough to retain an atmosphere through gravity alone and large enough that its molten core remains a heat engine, driving the diverse geology of the surface (the decay of radioactive elements within a planet's core is the other significant component of planetary heating). Mars, by contrast, is nearly (or perhaps totally) geologically dead and has lost much of its atmosphere. Thus, it would be fair to infer that the lower mass limit for habitability lies somewhere between that of Mars and Earth or Venus; 0.3 Earth masses has been offered as a rough dividing line for habitable planets. However, a 2008 study by the Harvard-Smithsonian Center for Astrophysics suggests that the dividing line may be higher. Earth may in fact lie on the lower boundary of habitability, since if it were any smaller, plate tectonics would be impossible. Venus, which has 85 percent Earth's mass, shows no signs of tectonic activity. Conversely, "super-Earths", terrestrial planets with higher masses than Earth, would have higher levels of plate tectonics and thus be firmly placed in the habitable range. Exceptional circumstances do offer exceptional cases: Jupiter's moon Io (which is smaller than any of the terrestrial planets) is volcanically dynamic because of the gravitational stresses induced by its orbit, and its neighbor Europa may have a liquid ocean underneath a frozen shell also due to power generated from orbiting a gas giant. Saturn's Titan, meanwhile, has an outside chance of harbouring life, as it has retained a thick atmosphere and bio-chemical reactions are possible in the liquid methane on its surface. These satellites are exceptions, but they prove that mass as a habitability criterion cannot be considered definitive.

Finally, a larger planet is likely to have a large iron core. This allows for a magnetic field to protect the planet from stellar wind and cosmic radiation, which otherwise would tend to strip away planetary atmosphere and to bombard living things with ionized particles. Mass is not the only criterion for producing a magnetic field—as the planet must also rotate fast enough to produce a dynamo effect within its core—but it is a significant component of the process.

Orbit and rotation

As with other criteria, stability is the critical consideration in determining the effect of orbital and rotational characteristics on planetary habitability. Orbital eccentricity is the difference between a planet's farthest and closest approach to its parent star divided by the sum of said distances. It is a ratio describing the shape of the elliptical orbit. The greater the eccentricity the greater the temperature fluctuation on a planet's surface. Although they are adaptive, living organisms can only stand so much variation, particularly if the fluctuations overlap both the freezing point and boiling point of the planet's main biotic solvent (e.g., water on Earth). If, for example, Earth's oceans were alternately boiling and freezing solid, it is difficult to imagine life as we know it having evolved. The more complex the organism, the greater the temperature sensitivity. The Earth's orbit is almost wholly circular, with an eccentricity of less than 0.02; other planets in our solar system (with the exception of Mercury) have eccentricities that are similarly benign.

Data collected on the orbital eccentricities of extrasolar planets has surprised most researchers: 90% have an orbital eccentricity greater than that found within the solar system, and the average is fully 0.25.

A planet's movement around its rotational axis must also meet certain criteria if life is to have the opportunity to evolve. A first assumption is that the planet should have moderate seasons. If there is little or no axial tilt (or obliquity) relative to the perpendicular of the ecliptic, seasons will not occur and a main stimulant to biospheric dynamism will disappear. The planet would also be colder than it would be with a significant tilt: when the greatest intensity of radiation is always within a few degrees of the equator, warm weather cannot move poleward and a planet's climate becomes dominated by colder polar weather systems.

If a planet is radically tilted, meanwhile, seasons will be extreme and make it more difficult for a biosphere to achieve homeostasis. Although during the Quaternary higher axial tilt of the Earth coincides with reduced polar ice, warmer temperatures and *less* seasonal variation, scientists do not know whether this trend would continue indefinitely with further increases in axial tilt.

The exact effects of these changes can only be computer modelled at present, and studies have shown that even extreme tilts of up to 85 degrees do not absolutely preclude life "provided it does not occupy continental surfaces plagued seasonally by the highest temperature." Not only the mean axial tilt, but also its variation over time must be considered. The Earth's tilt varies between 21.5 and 24.5 degrees over 41,000 years. A more drastic variation, or a much shorter periodicity, would induce climatic effects such as variations in seasonal severity.

Other orbital considerations include:

- The planet should rotate relatively quickly so that the day-night cycle is not overlong. If a day takes years, the temperature differential between the day and

night side will be pronounced, and problems similar to those noted with extreme orbital eccentricity will come to the fore.
- The planet should also rotate quickly enough so that a magnetic dynamo may be started in its iron core to produce a magnetic field.
- Change in the direction of the axis rotation (precession) should not be pronounced. In itself, precession need not affect habitability as it changes the direction of the tilt, not its degree. However, precession tends to accentuate variations caused by other orbital deviations.

The Earth's Moon appears to play a crucial role in moderating the Earth's climate by stabilising the axial tilt. It has been suggested that a chaotic tilt may be a "deal-breaker" in terms of habitability— i.e. a satellite the size of the moon is not only helpful but required to produce stability. This position remains controversial.[g]

Geochemistry

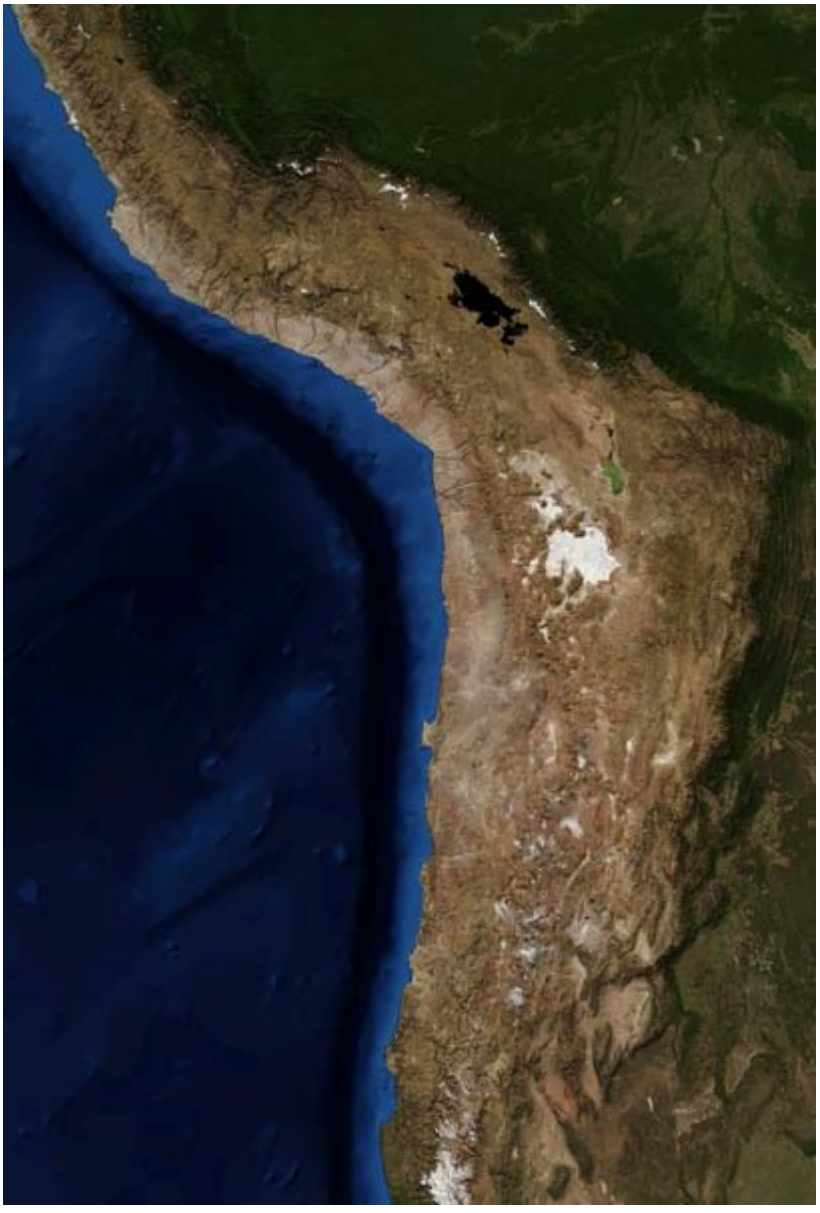
It is generally assumed that any extraterrestrial life that might exist will be based on the same fundamental biochemistry as found on Earth, as the four elements most vital for life, carbon, hydrogen, oxygen, and nitrogen, are also the most common chemically reactive elements in the universe. Indeed, simple biogenic compounds, such as amino acids, have been found in meteorites and in the interstellar medium. These four elements together comprise over 96% of Earth's collective biomass. Carbon has an unparalleled ability to bond with itself and to form a massive array of intricate and varied structures, making it an ideal material for the complex mechanisms that form living cells. Hydrogen and oxygen, in the form of water, compose the solvent in which biological processes take place and in which the first reactions occurred that led to life's emergence. The energy released in the formation of powerful covalent bonds between carbon and oxygen, available by oxidizing organic compounds, is the fuel of all complex life-forms. These four elements together make up amino acids, which in turn are the building blocks of proteins, the substance of living tissue. In addition, neither sulfur, required for the building of proteins, nor phosphorus, needed for the formation of DNA, RNA, and the adenosine phosphates essential to metabolism, are rare.

Relative abundance in space does not always mirror differentiated abundance within planets; of the four life elements, for instance, only oxygen is present in any abundance in the Earth's crust. This can be partly explained by the fact that many of these elements, such as hydrogen and nitrogen, along with their simplest and most common compounds, such as carbon dioxide, carbon monoxide, methane, ammonia, and water, are gaseous at warm temperatures. In the hot region close to the Sun, these volatile compounds could not have played a significant role in the planets' geological formation. Instead, they were trapped as gases underneath the newly formed crusts, which were largely made of rocky, involatile compounds such as silica (a compound of silicon and oxygen, accounting for oxygen's relative abundance). Outgassing of volatile compounds through the first volcanoes would have contributed to the formation of the planets' atmospheres. The Miller-Urey experiment showed that, with the application of energy, amino acids can form from the synthesis of the simple compounds within a primordial atmosphere.

Even so, volcanic outgassing could not have accounted for the amount of water in Earth's oceans. The vast majority of the water —and arguably carbon— necessary for life must have come from the outer solar system, away from the Sun's heat, where it could remain solid. Comets impacting with the Earth in the Solar system's early years would have deposited vast amounts of water, along with the other volatile compounds life requires (including amino acids) onto the early Earth, providing a kick-start to the origin of life.

Thus, while there is reason to suspect that the four "life elements" ought to be readily available elsewhere, a habitable system probably also requires a supply of long-term orbiting bodies to seed inner planets. Without comets there is a possibility that life as we know it would not exist on Earth.

Microenvironments and extremophiles



The Atacama Desert provides an analog to Mars and an ideal environment to study the boundary between sterility and habitability.

One important qualification to habitability criteria is that only a tiny portion of a planet is required to support life. Astrobiologists often concern themselves with "micro-environments," noting that "we lack a fundamental understanding of how evolutionary forces, such as mutation, selection, and genetic drift, operate in micro-organisms that act on and respond to changing micro-environments." Extremophiles are Earth organisms that live in niche environments under severe conditions generally considered inimical to life. Usually (although not always) unicellular, extremophiles include acutely alkaliphilic and acidophilic organisms and others that can survive water temperatures above 100 °C in hydrothermal vents.

The discovery of life in extreme conditions has complicated definitions of habitability, but also generated much excitement amongst researchers in greatly broadening the known range of conditions under which life can persist. For example, a planet that might otherwise be unable to support an atmosphere given the solar conditions in its vicinity, might be able to do so within a deep shadowed rift or volcanic cave. Similarly, craterous terrain might offer a refuge for primitive life. The Lawn Hill crater has been studied as an astrobiological analog, with researchers suggesting rapid sediment infill created a protected microenvironment for microbial organisms; similar conditions may have occurred over the geological history of Mars.

Earth environments that *cannot* support life are still instructive to astrobiologists in defining the limits of what organisms can endure. The heart of the Atacama desert, generally considered the driest place on Earth, appears unable to support life, but it has been subject to study by NASA for that reason: it provides a Mars analog and the moisture gradients along its edges are ideal for studying the boundary between sterility and habitability. The Atacama was the subject of study in 2003 that partly replicated experiments from the Viking landings on Mars in the 1970s; no DNA could be recovered from two soil samples, and incubation experiments were also negative for biosignatures.

Alternative star systems

In determining the feasibility of extraterrestrial life, astronomers had long focused their attention on stars like our own Sun. However, they have begun to explore the possibility that life might form in systems very unlike our own.

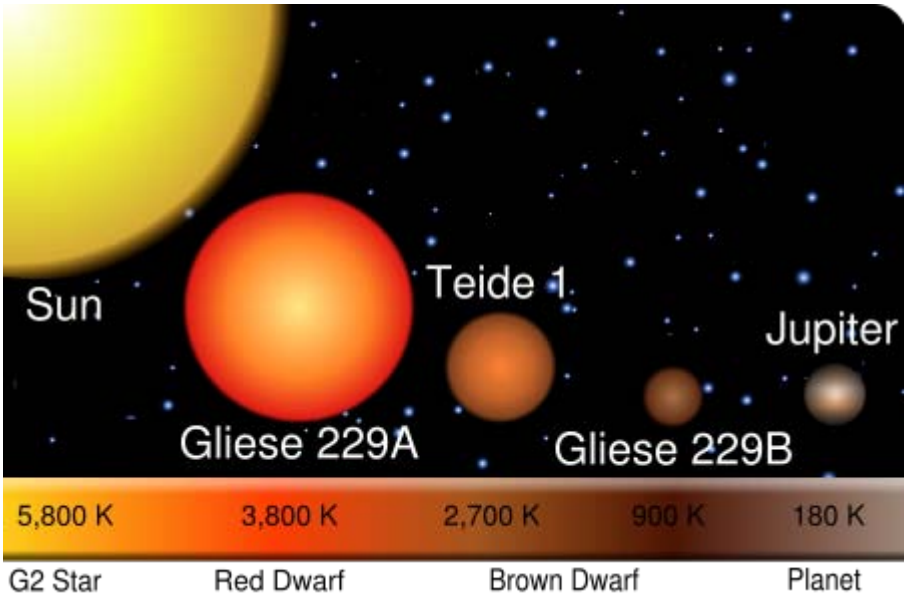
Binary systems

Typical estimates often suggest that 50% or more of all stellar systems are binary systems. This may be partly sample bias, as massive and bright stars tend to be in binaries and these are most easily observed and catalogued; a more precise analysis has suggested that the more common fainter stars are usually singular, and that up to two thirds of all stellar systems are therefore solitary.

The separation between stars in a binary may range from less than one astronomical unit (AU, the Earth-Sun distance) to several hundred. In latter instances, the gravitational effects will be negligible on a planet orbiting an otherwise suitable star and habitability potential will not be disrupted unless the orbit is highly eccentric. However, where the separation is significantly less, a stable orbit may be impossible. If a planet's distance to its primary exceeds about one fifth of the closest approach of the other star, orbital stability is not guaranteed. Whether planets might form in binaries at all had long been unclear, given that gravitational forces might interfere with planet formation. Theoretical work by Alan Boss at the Carnegie Institution has shown that gas giants can form around stars in binary systems much as they do around solitary stars.

One study of Alpha Centauri, the nearest star system to the Sun, suggested that binaries need not be discounted in the search for habitable planets. Centauri A and B have an 11 AU distance at closest approach (23 AU mean), and both should have stable habitable zones. A study of long-term orbital stability for simulated planets within the system shows that planets within approximately three AU of either star may remain stable (i.e. the semi-major axis deviating by less than 5%). The HZ for Centauri A is conservatively estimated at 1.2 to 1.3 AU and Centauri B at 0.73 to 0.74—well within the stable region in both cases.

Red dwarf systems



Relative star sizes and photospheric temperatures. Any planet around a red dwarf such as the one shown here would have to huddle close to achieve Earth-like temperatures, probably inducing tidal lock.

Determining the habitability of red dwarf stars could help determine how common life in the universe might be, as red dwarfs make up between 70 to 90% of all the stars in the galaxy. Brown dwarfs are probably more numerous than red dwarfs. However, they are

not generally classified as stars, and could never support life as we understand it, since what little heat they emit quickly disappears.

Astronomers for many years ruled out red dwarfs as potential abodes for life. Their small size (from 0.1 to 0.6 solar masses) means that their nuclear reactions proceed exceptionally slowly, and they emit very little light (from 3% of that produced by the Sun to as little as 0.01%). Any planet in orbit around a red dwarf would have to huddle very close to its parent star to attain Earth-like surface temperatures; from 0.3 AU (just inside the orbit of Mercury) for a star like Lacaille 8760, to as little as 0.032 AU for a star like Proxima Centauri (such a world would have a year lasting just 6.3 days). At those distances, the star's gravity would cause tidal lock. One side of the planet would eternally face the star, while the other would always face away from it. The only way potential life could avoid either an inferno or a deep freeze would be if the planet had an atmosphere thick enough to transfer the star's heat from the day side to the night side. It was long assumed that such a thick atmosphere would prevent sunlight from reaching the surface in the first place, preventing photosynthesis.

This pessimism has been tempered by research. Studies by Robert Haberle and Manoj Joshi of NASA's Ames Research Center in California have shown that a planet's atmosphere (assuming it included greenhouse gases CO_2 and H_2O) need only be 100 mbs, or 10% of Earth's atmosphere, for the star's heat to be effectively carried to the night side. This is well within the levels required for photosynthesis, though water would still remain frozen on the dark side in some of their models. Martin Heath of Greenwich Community College, has shown that seawater, too, could be effectively circulated without freezing solid if the ocean basins were deep enough to allow free flow beneath the night side's ice cap. Further research—including a consideration of the amount of photosynthetically active radiation—suggested that tidally locked planets in red dwarf systems might at least be habitable for higher plants.

Size is not the only factor in making red dwarfs potentially unsuitable for life, however. On a red dwarf planet, photosynthesis on the night side would be impossible, since it would never see the sun. On the day side, because the sun does not rise or set, areas in the shadows of mountains would remain so forever. Photosynthesis as we understand it would be complicated by the fact that a red dwarf produces most of its radiation in the infrared, and on the Earth the process depends on visible light. There are potential positives to this scenario. Numerous terrestrial ecosystems rely on chemosynthesis rather than photosynthesis, for instance, which would be possible in a red dwarf system. A static primary star position removes the need for plants to steer leaves toward the sun, deal with changing shade/sun patterns, or change from photosynthesis to stored energy during night. Because of the lack of a day-night cycle, including the weak light of morning and evening, far more energy would be available at a given radiation level.

Red dwarfs are far more variable and violent than their more stable, larger cousins. Often they are covered in starspots that can dim their emitted light by up to 40% for months at a time, while at other times they emit gigantic flares that can double their brightness in a matter of minutes. Such variation would be very damaging for life, as it would not only

destroy any complex organic molecules that could possibly form biological precursors, but also because it would blow off sizeable portions of the planet's atmosphere. For a planet around a red dwarf star to support life, it would require a rapidly rotating magnetic field to protect it from the flares. However, a tidally locked planet rotates only very slowly, and so cannot produce a geodynamo at its core. However, the violent flaring period of a red dwarf's life cycle is estimated to only last roughly the first 1.2 billion years of its existence. If a planet forms far away from a red dwarf so as to avoid tidal locking, and then migrates into the star's habitable zone after this turbulent initial period, it is possible that life may have a chance to develop.

There is, however, one major advantage that red dwarfs have over other stars as abodes for life: they live a long time. It took 4.5 billion years before humanity appeared on Earth, and life as we know it will see suitable conditions for at most 1 billion years more. Red dwarfs, by contrast, could live for trillions of years because their nuclear reactions are far slower than those of larger stars, meaning that life would have longer to evolve and survive. Further, while the odds of finding a planet in the habitable zone around any specific red dwarf are slim, the total amount of habitable zone around all red dwarfs combined is equal to the total amount around Sun-like stars given their ubiquity.

Massive stars

Recent research suggests that very large stars, greater than ~100 solar masses, could have planetary systems consisting of hundreds of Mercury-sized planets within the habitable zone. Such systems could also contain brown dwarfs and low-mass stars (~0.1-0.3 solar masses).

The galactic neighborhood

Along with the characteristics of planets and their star systems, the wider galactic environment may also impact habitability. Scientists considered the possibility that particular areas of galaxies (galactic habitable zones) are better suited to life than others; the solar system in which we live, in the Orion Spur, on the Milky Way galaxy's edge is considered to be in a life-favorable spot:

- It is not in a globular cluster where immense star densities are inimical to life, given excessive radiation and gravitational disturbance. Globular clusters are also primarily composed of older, probably metal-poor, stars.
- It is not near an active gamma ray source.
- It is not near the galactic center where once again star densities increase the likelihood of ionizing radiation (e.g., from magnetars and supernovae). A supermassive black hole is also believed to lie at the middle of the galaxy which might prove a danger to any nearby bodies.
- The circular orbit of the Sun around the galactic center keeps it out of the way of the galaxy's spiral arms where once more intense radiation and gravitation may lead to disruption.

Thus, relative loneliness is ultimately what a life-bearing system needs. If the Sun were crowded amongst other systems, the chance of being fatally close to dangerous radiation sources would increase significantly. Further, close neighbours might disrupt the stability of various orbiting bodies such as Oort cloud and Kuiper Belt objects, which can bring catastrophe if knocked into the inner solar system.

While stellar crowding proves disadvantageous to habitability, so too does extreme isolation. A star as metal-rich as the Sun would probably not have formed in the very outermost regions of the Milky Way given a decline in the relative abundance of metals and a general lack of star formation. Thus, a "suburban" location, such as our Solar System enjoys, is preferable to a Galaxy's center or farthest reaches.

Other considerations

Alternative biochemistries

While most investigations of extraterrestrial life start with the assumption that advanced life-forms must have similar requirements for life as on Earth, the hypothesis of other types of biochemistry suggests the possibility of lifeforms evolving around a different metabolic mechanism. In *Evolving the Alien*, biologist Jack Cohen and mathematician Ian Stewart argue astrobiology, based on the Rare Earth hypothesis, is restrictive and unimaginative. They suggest that Earth-like planets may be very rare, but non-carbon-based complex life could possibly emerge in other environments. The most frequently mentioned alternative to carbon is silicon-based life, while ammonia is sometimes suggested as an alternative solvent to water.

More speculative ideas have focused on bodies altogether different than Earth-like planets. Astronomer Frank Drake, a well-known proponent of the search for extraterrestrial life, imagined life on a neutron star: submicroscopic "nuclear molecules" combining to form creatures with a life cycle millions of times quicker than Earth life. Called "imaginative and tongue-in-cheek," the idea gave rise to science fiction depictions. Carl Sagan, another optimist with regards to extraterrestrial life, considered the possibility of organisms that are always airborne within the high atmosphere of Jupiter in a 1976 paper. Cohen and Stewart also envisioned life in both a solar environment and in the atmosphere of a gas giant.

"Good Jupiters"

"Good Jupiters" are gas giant planets, like the solar system's Jupiter, that orbit their stars in circular orbits far enough away from the habitable zone to not disturb it but close enough to "protect" terrestrial planets in closer orbit in two critical ways. First, they help to stabilize the orbits, and thereby the climates, of the inner planets. Second, they keep the inner solar system relatively free of comets and asteroids that could cause devastating impacts. Jupiter orbits the Sun at about five times the distance between the Earth and the Sun. This is the rough distance we should expect to find good Jupiters elsewhere. Jupiter's "caretaker" role was dramatically illustrated in 1994 when Comet Shoemaker-

Levy 9 impacted the giant; had Jovian gravity not captured the comet, it may well have entered the inner solar system.

Early in the Solar System's history, Jupiter played a somewhat contrary role: it increased the eccentricity of asteroid belt orbits and enabled many to cross Earth's orbit and supply the planet with important volatiles. Before Earth reached half its present mass, icy bodies from the Jupiter–Saturn region and small bodies from the primordial asteroid belt supplied water to the Earth due to the gravitational scattering of Jupiter and, to a lesser extent, Saturn. Thus, while the gas giants are now helpful protectors, they were once suppliers of critical habitability material.

In contrast, Jupiter-sized bodies that orbit too close to the habitable zone but not in it (as in 47 Ursae Majoris), or have a highly elliptical orbit that crosses the habitable zone (like 16 Cygni B) make it very difficult for an Earthlike planet to exist in the system.

Life's impact on habitability

A supplement to the factors that support life's emergence is the notion that life itself, once formed, becomes a habitability factor in its own right. An important Earth example was the production of oxygen by ancient cyanobacteria, and eventually photosynthesizing plants, leading to a radical change in the composition of Earth's atmosphere. This oxygen would prove fundamental to the respiration of later animal species.

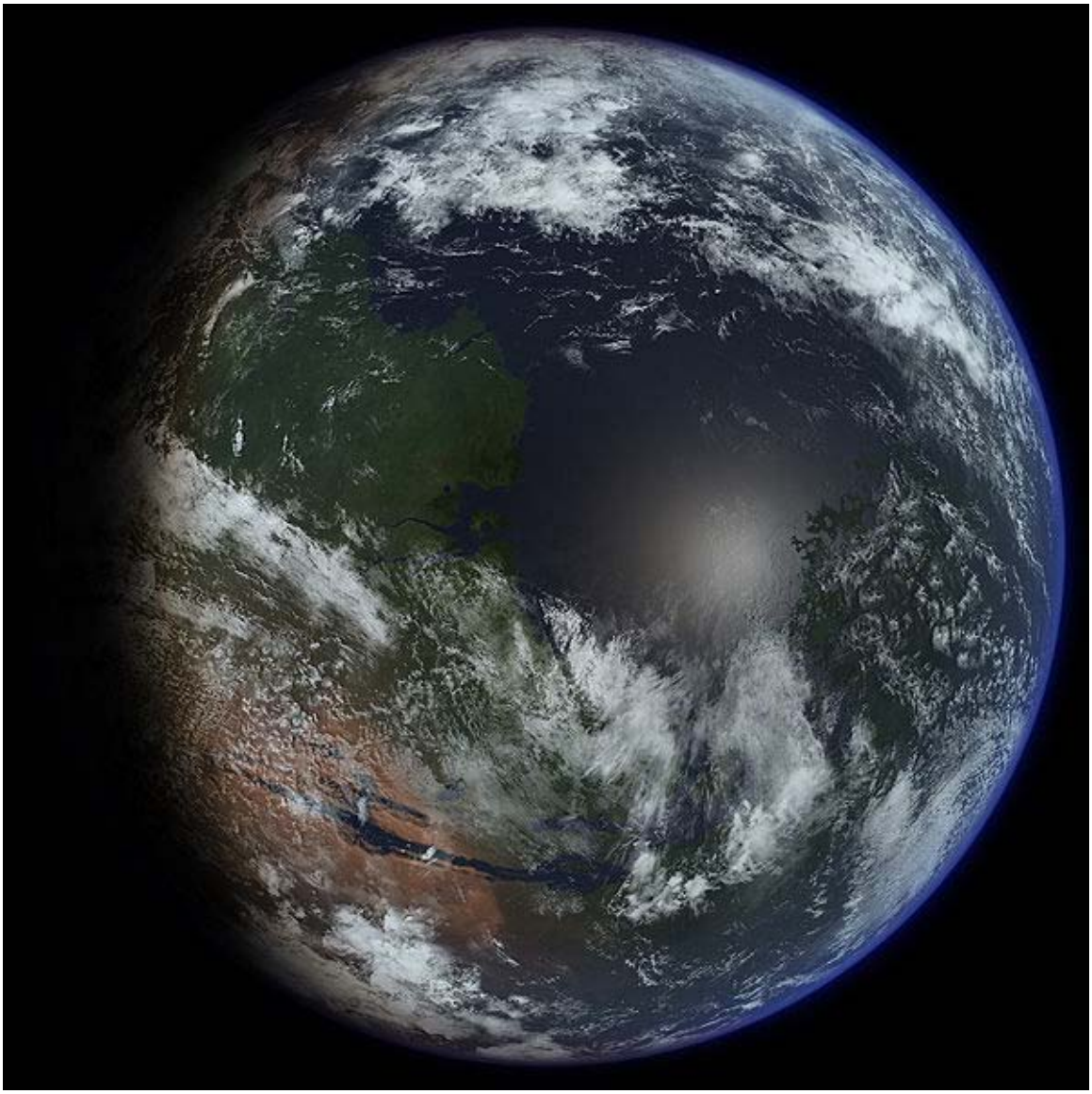
This interaction between life and subsequent habitability has been explored in various ways. The Gaia hypothesis, a class of scientific models of the geo-biosphere pioneered by Sir James Lovelock in 1975, argues that life as a whole fosters and maintains suitable conditions for itself by helping to create a planetary environment suitable for its continuity; at its most dramatic, Gaia suggests that planetary systems behave similarly to a kind of organism. The most successful life forms change the composition of the air, water, and soil in ways that make their continued existence more certain—a controversial extension of the accepted laws of ecology.

Similarly, David Grinspoon has suggested a "Living Worlds hypothesis" in which our understanding of what constitutes habitability cannot be separated from life already extant on a planet. Planets that are geologically and meteorologically alive are much more likely to be biologically alive as well and "a planet and its life will co-evolve."

In their 2004 book *The Privileged Planet*, astronomer Guillermo Gonzalez and philosopher Jay Richards explore the possible link between the habitability of a planet and its suitability for observing the rest of the universe. The book was criticized as an example of intelligent design and for its lack of scientific credibility.

Chapter- 8

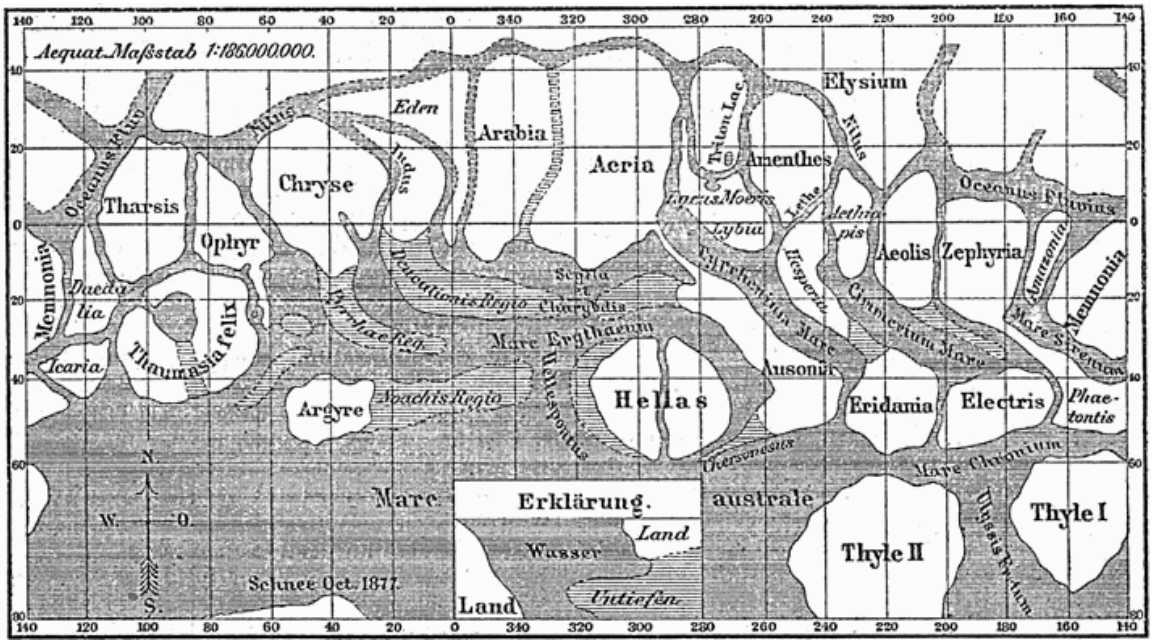
Life on Mars



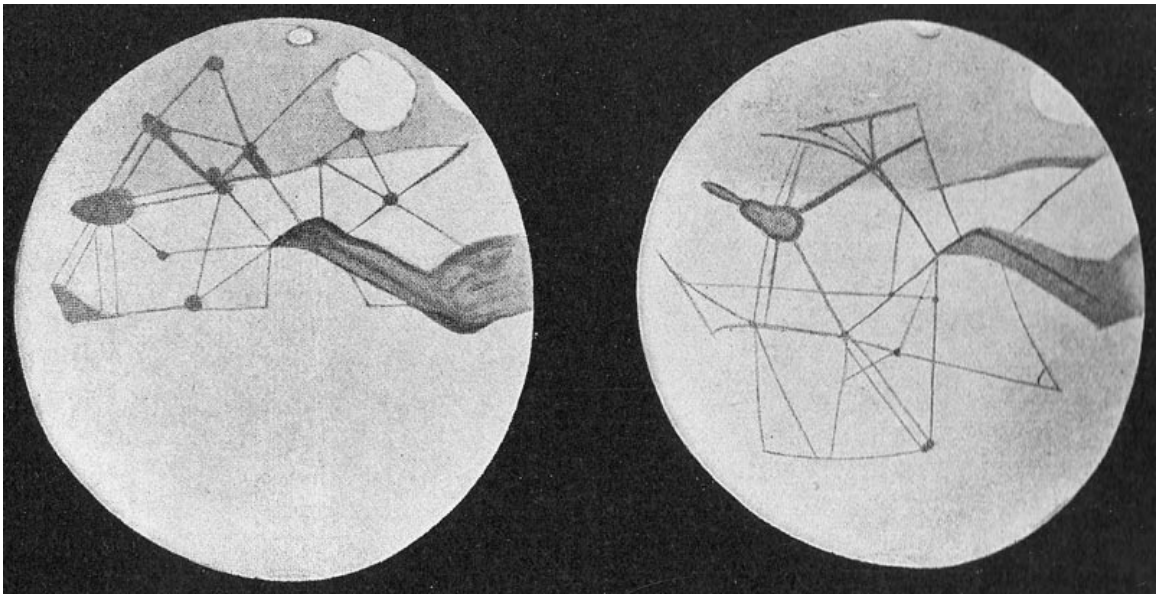
An artist's impression of what Mars' surface and atmosphere may look like if Mars were terraformed.

Scientists have long speculated about the possibility of **life on Mars** owing to the planet's proximity and similarity to Earth. Although fictional Martians have been a recurring feature of popular entertainment, it remains an open question whether life currently exists on Mars, or has existed there in the past.

Early speculation



Historical map of Mars from Giovanni Schiaparelli.



Mars canals, as seen by astronomer P. Lowell, 1898.

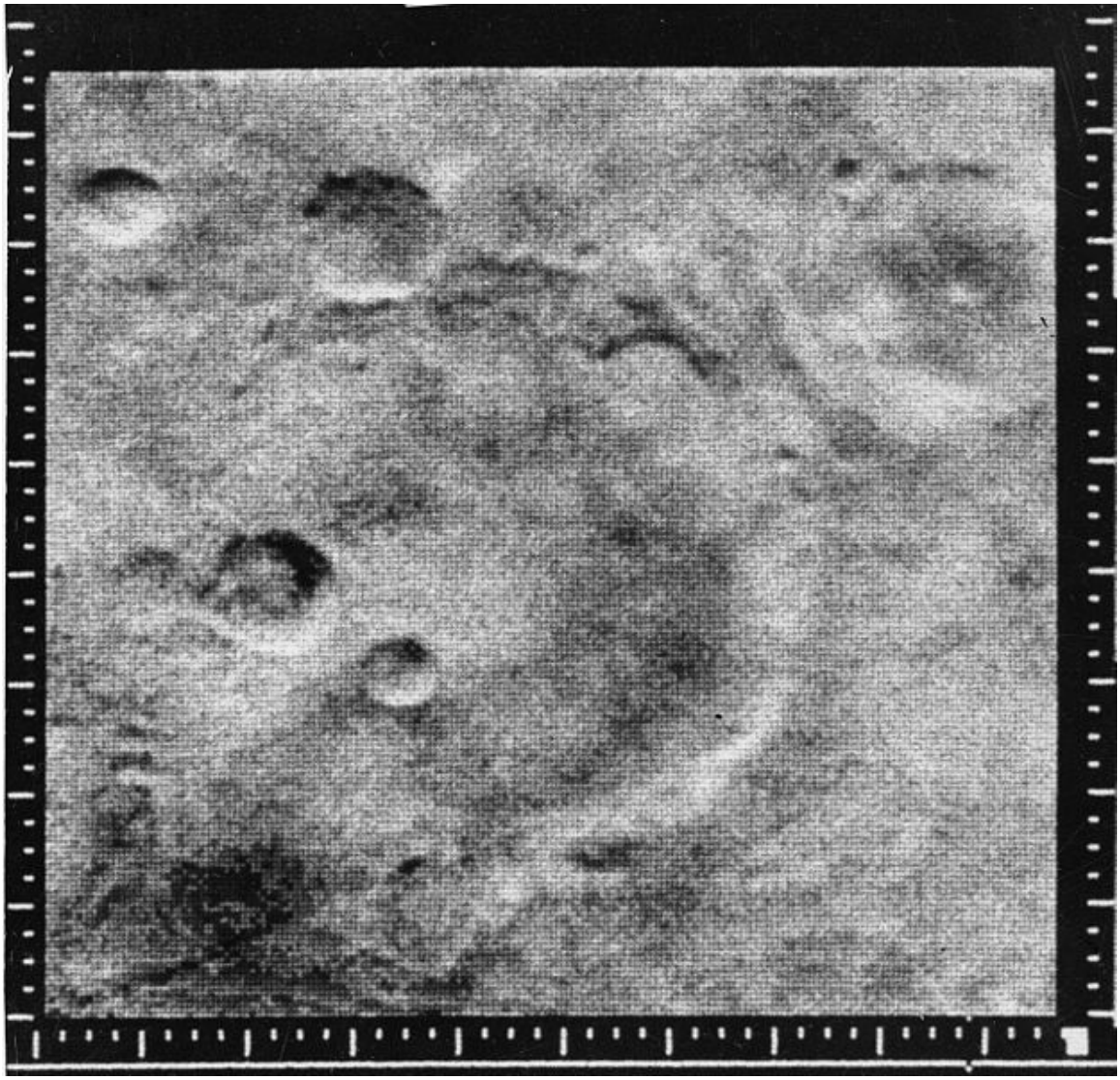
Mars' polar ice caps were observed as early as the mid-17th century, and they were first proven to grow and shrink alternately, in the summer and winter of each hemisphere, by William Herschel in the latter part of the 18th century. By the mid-19th century, astronomers knew that Mars had certain other similarities to Earth, for example that the length of a day on Mars was almost the same as a day on Earth. They also knew that its axial tilt was similar to Earth's, which meant it experienced seasons just as Earth does - but of nearly double the length owing to its much longer year. These observations led to the increase in speculation that the darker albedo features were water, and brighter ones were land. It was therefore natural to suppose that Mars may be inhabited by some form of life.

In 1854, William Whewell, a fellow of Trinity College, Cambridge, who popularized the word *scientist,* theorized that Mars had seas, land and possibly life forms. Speculation about life on Mars exploded in the late 19th century, following telescopic observation by some observers of apparent Martian canals — which were however soon found to be optical illusions. Despite this, in 1895, American astronomer Percival Lowell published his book *Mars,* followed by *Mars and its Canals* in 1906, proposing that the canals were the work of a long-gone civilization. This idea led British writer H. G. Wells to write *The War of the Worlds* in 1897, telling of an invasion by aliens from Mars who were fleeing the planet’s desiccation.

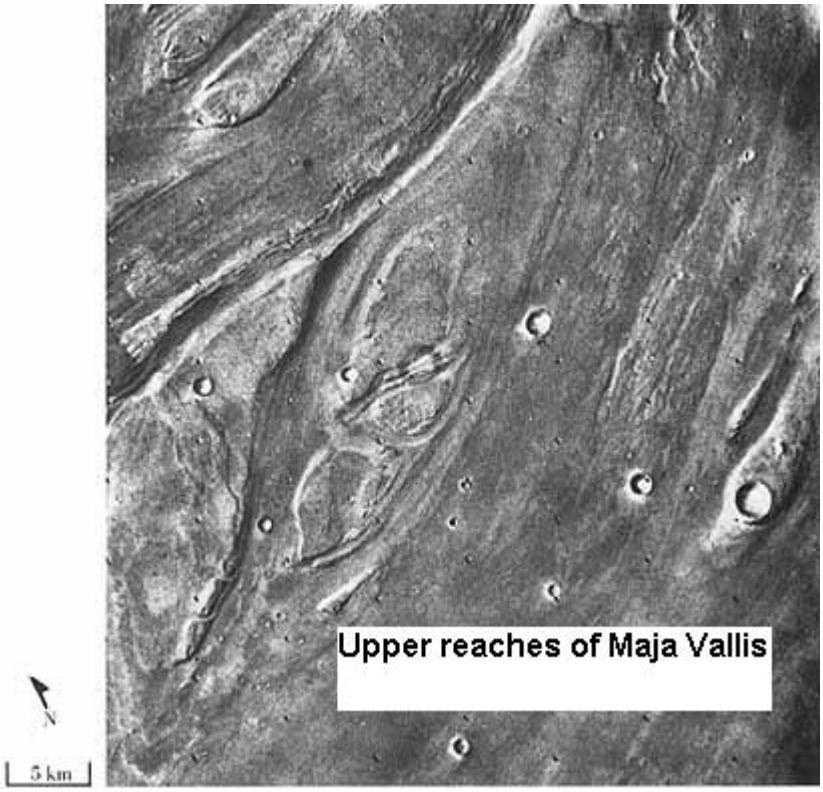
Spectroscopic analysis of Mars' atmosphere began in earnest in 1894, when U.S. astronomer William Wallace Campbell showed that neither water nor oxygen were present in the Martian atmosphere. By 1909 better telescopes and the best perihelic opposition of Mars since 1877 conclusively put an end to the canal theory.

Missions

Mariner 4



Mariner Crater, as seen by Mariner 4 in 1965. Pictures like this suggested that Mars is too dry for any kind of life.



Streamlined Islands seen by Viking orbiter showed that large floods occurred on Mars. Image is located in Lunae Palus quadrangle.

Mariner 4 probe performed the first successful flyby of the planet Mars, returning the first pictures of the Martian surface in 1965. The photographs showed an arid Mars without rivers, oceans or any signs of life. Further, it revealed that the surface (at least the parts that it photographed) was covered in craters, indicating a lack of plate tectonics and weathering of any kind for the last 4 billion years. The probe also found that Mars has no global magnetic field that would protect the planet from potentially life-threatening cosmic rays. The probe was able to calculate the atmospheric pressure on the planet to be about 0.6 kPa (compared to Earth's 101.3 kPa), meaning that liquid water could not exist on the planet's surface. After Mariner 4, the search for life on Mars changed to a search for bacteria-like living organisms rather than for multicellular organisms, as the environment was clearly too harsh for these.

Viking orbiters

Liquid water is necessary for life and metabolism, so if water was present on Mars, the chances of it having supported life may have been determinant. The Viking orbiters found evidence of possible river valleys in many areas, erosion and, in the southern hemisphere, branched streams.

Carl Sagan poses next to a replica of the Viking landers.

Viking experiments

The primary mission of the Viking probes of the mid-1970s was to carry out experiments designed to detect microorganisms in Martian soil. The tests were formulated to look for life similar to that found on Earth. Of the four experiments, only the Labeled Release (LR) experiment returned a positive result, showing increased $^{14}CO_2$ production on first exposure of soil to water and nutrients. All scientists agree on two points from the Viking missions: that radiolabeled $^{14}CO_2$ was evolved in the Labeled Release experiment, and that the GC-MS detected no organic molecules. However, there are vastly different interpretations of what those results imply.

One of the designers of the Labeled Release experiment, Gilbert Levin, believes his results are a definitive diagnostic for life on Mars. However, this result is disputed by many scientists, who argue that superoxidant chemicals in the soil could have produced this effect without life being present. An almost general consensus discarded the Labeled Release data as evidence of life, because the gas chromatograph & mass spectrometer, designed to identify natural organic matter, did not detect organic molecules. The results of the Viking mission concerning life are considered by the general expert community, at best, as inconclusive.

In 2007, during a Seminar of the Geophysical Laboratory of the Carnegie Institution (Washington, D.C., USA), Gilbert Levin's investigation was assessed once more. Levin

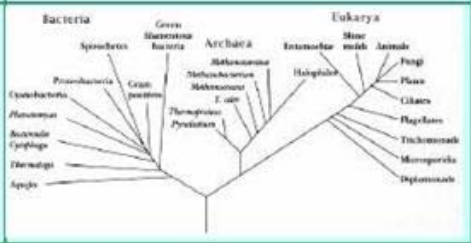
maintains that his original data were correct, as the positive and negative control experiments were in order.

Ronald Paepe, an edaphologist (soil scientist), communicated to the European Geosciences Union Congress that the discovery of the recent detection of phyllosilicate clays on Mars may indicate pedogenesis, or soil development processes, extended over the entire surface of Mars. Paepe's interpretation views most of Mars surface as active soil, colored red by eons of widespread wearing by water, vegetation and microbial activity.

A research team from the Salk Institute for Biological Studies headed by Rafael Navarro-González, concluded that the equipment used (TV-GC-MS) by the Viking program to search for organic molecules, may not be sensitive enough to detect low levels of organics. Because of the simplicity of sample handling, TV–GC–MS is still considered the standard method for organic detection on future Mars missions, Navarro-González suggests that the design of future organic instruments for Mars should include other methods of detection.

Gillevinia straata

Table 2. Life's major domains (*) and formal systematic position of the active agent characterized by its reported behavior as responsible of the results of the 1976 Viking Mission's Labeled Release experiment.

Organic Life System	*Biosphere*	*Domains*	*Middle taxa*	*Known Genera & Species*
Solaria	Terrestria		…	Many
	Marciana	Jakobia	…	Levinia straata

* Observational knowledge about Solaria's biospheres is unbalanced; about extra-Solaria biospheres, unexisting.

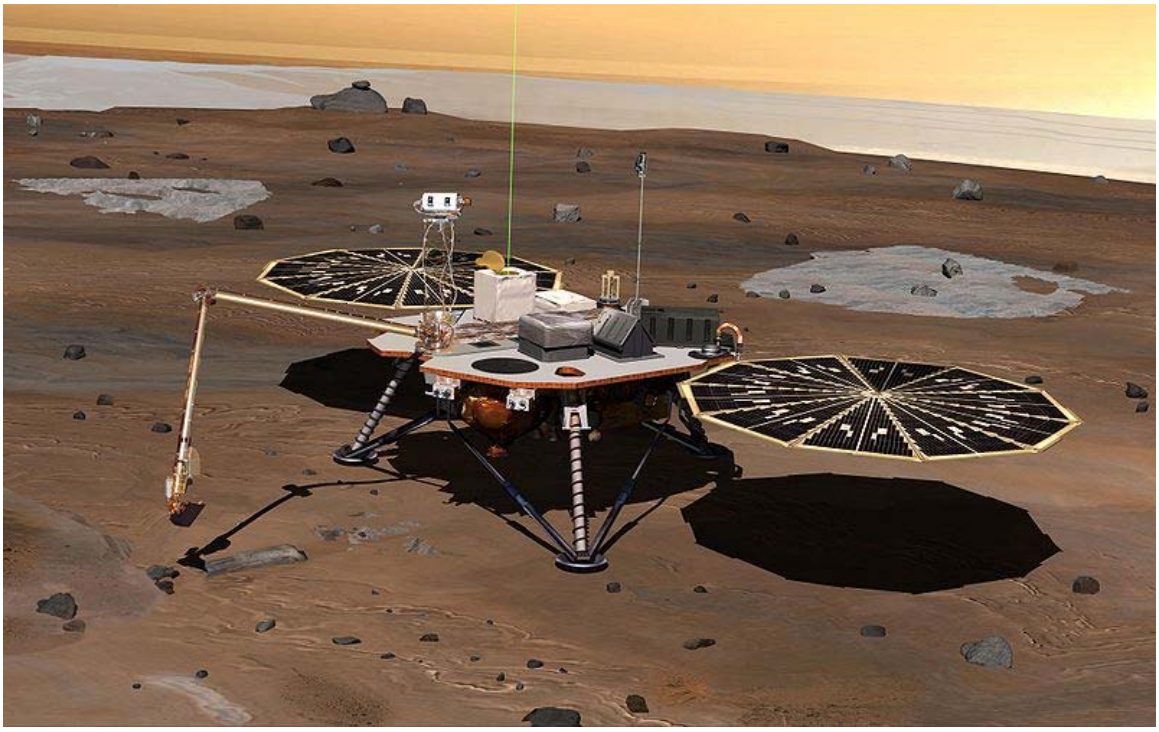
Newly proposed taxonomic system.

The claim for life on Mars, in the form of *Gillevinia straata*, is based on old data reinterpreted as sufficient evidence of life, mainly by professors Gilbert Levin, Rafael Navarro-González and Ronalds Paepe. The evidence supporting the existence of *Gillevinia straata* microorganisms relies on the data collected by the two Mars *Viking* landers that searched for biosignatures of life, but the analytical results were, officially, inconclusive.

In 2006, Mario Crocco, a neurobiologist at the Neuropsychiatric Hospital Borda in Buenos Aires, Argentina, proposed the creation of a new nomenclatural rank that classified the Viking landers' results as 'metabolic' and therefore belonging to a form of life. Crocco proposed to create new biological ranking categories (taxa), in the new kingdom system of life, in order to be able to accommodate the genus of Martian microorganisms. Crocco proposed the following taxonomical entry:

- Organic life system: Solaria
- Biosphere: Marciana
- Kingdom: Jakobia (named after neurobiologist Christfried Jakob)
- Genus et species: *Gillevinia straata*

As a result, the hypothetical *Gillevinia straata* would not be a bacterium (which rather is a terrestrial taxon) but a member of the kingdom 'Jakobia' in the biosphere 'Marciana' of the 'Solaria' system. The intended effect of the new nomenclature was to reverse the burden of proof concerning the life issue, but the taxonomy proposed by Crocco has not been accepted by the scientific community and is considered a single *nomen nudum*. Further, no Mars mission has found traces of biomolecules.



An artist's concept of the Phoenix spacecraft.

Phoenix lander, 2008

The Phoenix mission landed a robotic spacecraft in the polar region of Mars on May 25, 2008 and it operated until November 10, 2008. One of the mission's two primary objectives was to search for a 'habitable zone' in the Martian regolith where microbial life

could exist, the other main goal being to study the geological history of water on Mars. The lander has a 2.5 meter robotic arm that was capable of digging shalow trenches in the regolith. There is an electrochemistry experiment which analysed the ions in the regolith and the amount and type of antioxidants on Mars. The Viking program data indicate that oxidants on Mars may vary with latitude, noting that Viking 2 saw fewer oxidants than Viking 1 in its more northerly position. Phoenix landed further north still. Phoenix's preliminary data revealed that Mars soil contains perchlorate, and thus may not be as life-friendly as thought earlier. The pH and salinity level were viewed as benign from the standpoint of biology. The analysers also indicated the presence of bound water and CO_2.

Future missions

- Mars Science Laboratory, a NASA project planned for launch in late 2011, will contain instruments and experiments designed to look for past or present conditions relevant to biological activity.

- ExoMars is a European-led multi-spacecraft programme currently under development by the European Space Agency (ESA) and NASA for launch in 2016 and 2018. Its primary scientific mission will be to search for possible biosignatures on Mars, past or present. Two rovers with a 2 m core drill each will be used to sample various depths beneath the surface where liquid water may be found and where microorganisms might survive cosmic radiation.

- Mars Sample Return Mission — The best life detection experiment proposed is the examination on Earth of a soil sample from Mars. However, the difficulty of providing and maintaining life support over the months of transit from Mars to Earth remains to be solved. Providing for still unknown environmental and nutritional requirements is daunting. Should dead organisms be found in a sample, it would be difficult to conclude that those organisms were alive when obtained.

Meteorites

NASA maintains a catalog of 34 Mars meteorites. These assets are highly valuable since they are the only physical samples available of Mars. Studies conducted by NASA's Johnson Space Center show that at least three of the meteorites contain potential evidence of past life on Mars, in the form of microscopic structures resembling fossilized bacteria (so-called biomorphs). Although the scientific evidence collected is reliable, its interpretation varies. To date, none of the original lines of scientific evidence for the hypothesis that the biomorphs are of exobiological origin (the so-called biogenic hypothesis) have been either discredited or positively ascribed to non-biological explanations.

Over the past few decades, seven criteria have been established for the recognition of past life within terrestrial geologic samples. Those criteria are:

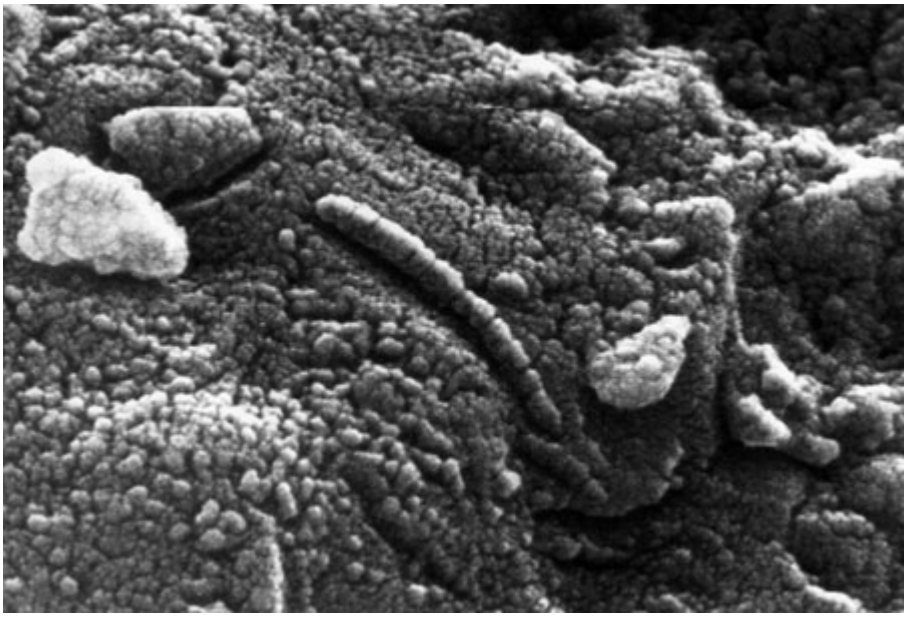
1. Is the geologic context of the sample compatible with past life?

2. Is the age of the sample and its stratigraphic location compatible with possible life?
3. Does the sample contain evidence of cellular morphology and colonies?
4. Is there any evidence of biominerals showing chemical or mineral disequilibria?
5. Is there any evidence of stable isotope patterns unique to biology?
6. Are there any organic biomarkers present?
7. Are the features indigenous to the sample?

For general acceptance of past life in a geologic sample, essentially most or all of these criteria must be met. All seven criteria have not yet been met for any of the Martian samples, but continued investigations are in progress.

As of 2010, reexaminations of the biomorphs found in the three Martian meteorites are underway with more advanced analytical instruments than previously available. The scientists conducting the study at Johnson Space Center believed that before the end of the year they would find in the meteorites definitive evidence for past life on Mars.

ALH84001 meteorite



An electron microscope reveals bacteria-like structures in meteorite fragment ALH84001

The ALH84001 meteorite was found on December 1984 on Antarctica, by members of the ANSMET project; the meteorite weighs 1.93 kilograms (4.3 lb). The sample was ejected from Mars about 17 million years ago and spent 11,000 years in or on the Antarctic ice sheets. Composition analysis by NASA revealed a kind of magnetite that on Earth, is only found in association with certain microorganisms; Then, in August 2002, another NASA team led by Thomas-Keptra published a study indicating that 25% of the magnetite in ALH 84001 occurs as small, uniform-sized crystals that, on Earth, is associated only with biologic activity, and that the remainder of the material appears to

be normal inorganic magnetite. The extraction technique did not permit determination as to whether the possibly biological magnetite was organized into chains as would be expected. The meteorite displays indication of relatively low temperature secondary mineralization by water and show evidence of preterrestrial aqueous alteration. Evidence of polycyclic aromatic hydrocarbons (PAHs) have been identified with the levels increasing away from the surface.

Some structures resembling the mineralized casts of terrestrial bacteria and their appendages (fibrils) or by-products (extracellular polymeric substances) occur in the rims of carbonate globules and preterrestrial aqueous alteration regions. The size and shape of the objects is consistent with Earthly fossilized nanobacteria, but the existence of nanobacteria itself is controversial.

In November 2009, NASA scientists said that a recent, more detailed analysis showed that the meteorite "contains strong evidence that life may have existed on ancient Mars".

Nakhla meteorite

Nakhla Meteorite

The Nakhla meteorite fell on Earth on June 28, 1911 on the locality of Nakhla, Alexandria, Egypt.

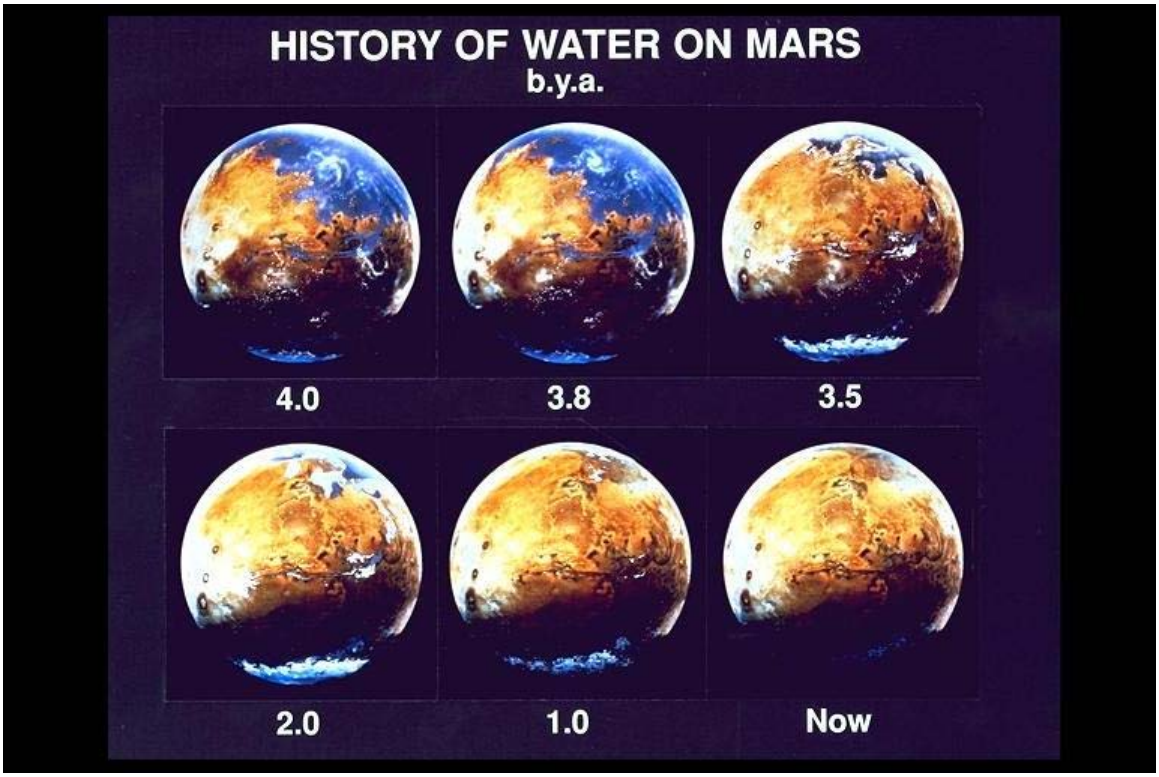
In 1998, a team from NASA's Johnson Space Center obtained a small sample for analysis. Researchers found preterrestrial aqueous alteration phases and objects of the size and shape consistent with Earthly fossilized nanobacteria, but the existence of nanobacteria itself is controversial. Analysis with gas chromatography and mass spectrometry (GC-MS) studied its high molecular weight polycyclic aromatic hydrocarbons in 2000, and NASA scientists concluded that as much as 75% of the organic matter in Nakhla "may not be recent terrestrial contamination".

This caused additional interest in this meteorite, so on 2006, NASA managed to obtain an additional and larger sample from the London Natural History Museum. On this second sample, a large dendritic carbon content was observed. When the results and evidence were published on 2006, some independent researchers claimed that the carbon deposits are of biologic origin. However, it was remarked that since carbon is the fourth most abundant element in the Universe, finding it in curious patterns is not indicative or suggestive of biological origin.

Shergotty meteorite

The Shergotty meteorite, a 4 kg martian meteorite, fell on Earth on Shergotty, India on August 25, 1865 and was retrieved by witnesses almost immediately. This meteorite is relatively young, calculated to have been formed in Mars only 165 million years ago from volcanic origin. It is composed mostly of pyroxene and thought to have undergone preterrestrial aqueous alteration for several centuries. Certain features in its interior suggest to be remnants of biofilm and their associated microbial communities. Work is in progress on searching for magnetites within alteration phases.

Liquid water



A series of artist's conceptions of hypothetical past water coverage on Mars.

No Mars probe since Viking has tested the Martian regolith specifically for metabolism which is the ultimate sign of current life. NASA's recent missions have focused on another question: whether Mars held lakes or oceans of liquid water on its surface in the ancient past. Scientists have found hematite, a mineral that forms in the presence of water. Thus, the mission of the Mars Exploration Rovers of 2004 was not to look for present or past life, but for evidence of liquid water on the surface of Mars in the planet's ancient past.

Since Mars lost most of its magnetic field about 4 billion years ago, the Martian ionosphere is unable to stop the solar wind or radiation, and it interacts directly with exposed soil, making life, as we know it, impossible to exist. Also, liquid water, necessary for life and for metabolism, cannot exist on the surface of Mars under its present low atmospheric pressure and temperature, except at the lowest shaded elevations for short periods and liquid water does not appear at the surface itself.

In June 2000, evidence for water currently under the surface of Mars was discovered in the form of flood-like gullies. Deep subsurface water deposits near the planet's liquid core might form a present-day habitat for life. However, in March 2006, astronomers announced the discovery of similar gullies on the Moon, which is believed never to have had liquid water on its surface. The astronomers suggest that the gullies could be the result of micrometeorite impacts.

In March 2004, NASA announced that its rover *Opportunity* had discovered evidence that Mars was, in the ancient past, a wet planet. This had raised hopes that evidence of past life might be found on the planet today. ESA confirmed that the Mars Express orbiter had directly detected huge reserves of water ice at Mars' south pole in January 2004.

On July 28, 2005, ESA announced that they had recorded photographic evidence of surface water ice near Mars' North pole.

In December 2006, NASA showed images taken by the Mars Global Surveyor that suggested that water occasionally flows on the surface of Mars. The images did not actually show flowing water. Rather, they showed changes in craters and sediment deposits, providing the strongest evidence yet that water coursed through them as recently as several years ago, and is perhaps doing so even now. Some researchers were skeptical that liquid water was responsible for the surface feature changes seen by the spacecraft. They said other materials such as sand or dust can flow like a liquid and produce similar results.

Recent analysis of Martian sandstones, using data obtained from orbital spectrometry, suggests that the waters that previously existed on the surface of Mars would have had too high a salinity to support most Earth-like life. Tosca *et al.* found that the Martian water in the locations they studied all had water activity, $a_w \leq 0.78$ to 0.86—a level fatal to most Terrestrial life. Haloarchaea, however, are able to live in hypersaline solutions, up to the saturation point.

The Phoenix Mars lander from NASA, which landed in the Mars Arctic plain in May 2008, confirmed the presence of frozen water near the surface. This was confirmed when bright material, exposed by the digging arm of the lander, was found to have vaporized and disappeared in 3 to 4 days. This has been attributed to sub-surface ice, exposed by the digging and sublimated on exposure to the atmosphere.

Methane

Trace amounts of methane in the atmosphere of Mars were discovered in 2003 and verified in 2004. The presence of methane indicates, as it is an unstable gas, that there must be an active source on the planet in order to keep such levels in the atmosphere. It is estimated that Mars must produce 270 ton/year of methane, but asteroid impacts account for only 0.8% of the total methane production. Although geologic sources of methane such as serpentinization are possible, the lack of current volcanism, hydrothermal activity or hotspots are not favorable for geologic methane. It has been suggested that the methane was produced by chemical reactions in meteorites, driven by the intense heat during entry through the atmosphere. However, research published in December 2009, ruled out this possibility.

The existence of life in the form of microorganisms such as methanogens are among possible but as yet unproven sources. If microscopic Martian life is producing the

methane, it likely resides far below the surface, where it is still warm enough for liquid water to exist.

Since the 2003 discovery of methane in the atmosphere, some scientists have been designing models and *in vitro* experiments testing growth of methanogenic bacteria on simulated Martian soil, where all four methanogen strains tested produced substantial levels of methane, even in the presence of 1.0wt% perchlorate salt. The results reported indicate that the perchlorates discovered by the Phoenix Lander would not rule out the possible presence of methanogens on Mars.

A team led by Levin suggested that both phenomena—methane production and degradation—could be accounted for by an ecology of methane-producing and methane-consuming microorganisms.

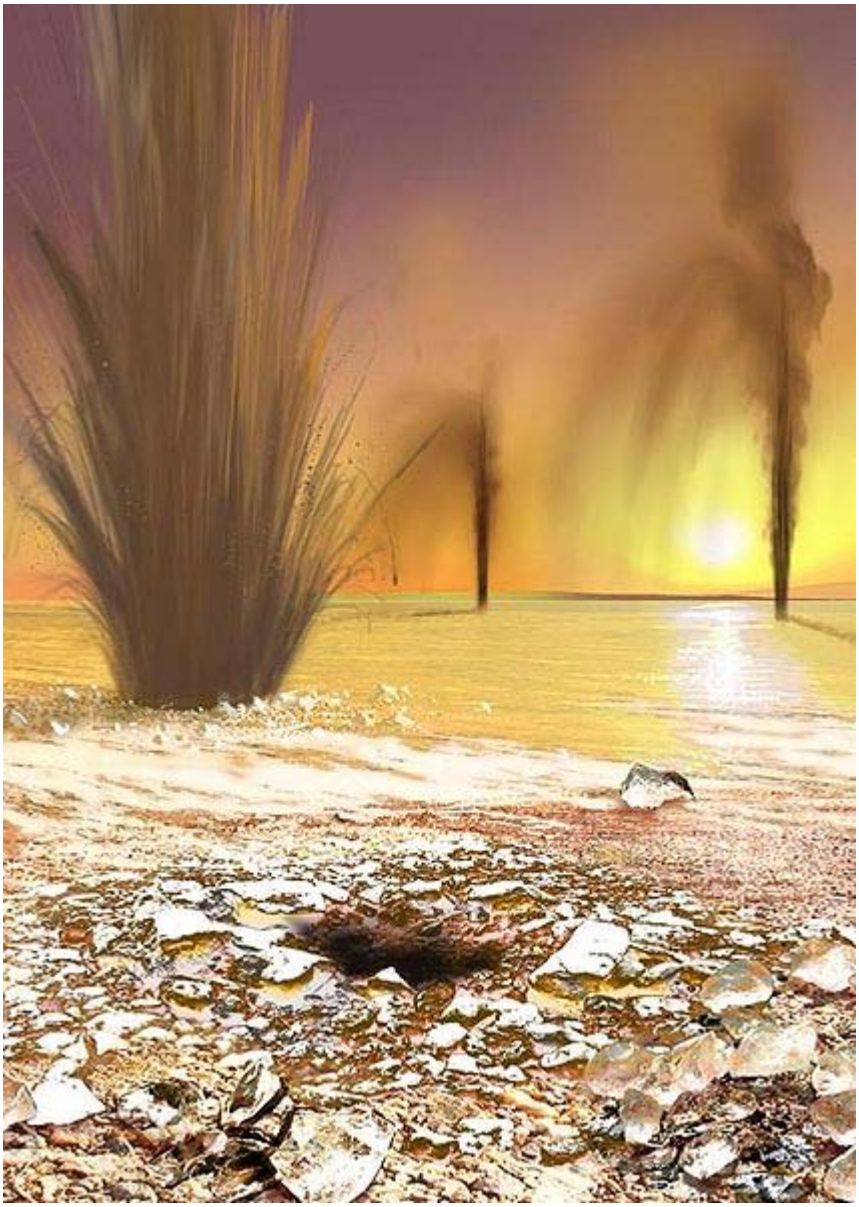
Formaldehyde

In February 2005, it was announced that the Planetary Fourier Spectrometer (PFS) on the European Space Agency's Mars Express Orbiter, detected traces of formaldehyde in the atmosphere of Mars. Vittorio Formisano, the director of the PFS, has speculated that the formaldehyde could be the byproduct of the oxidation of methane, and according to him, would provide evidence that Mars is either extremely geologically active, or harbouring colonies of microbial life. NASA scientists consider the preliminary findings are well worth a follow-up, but have also rejected the claims of life.

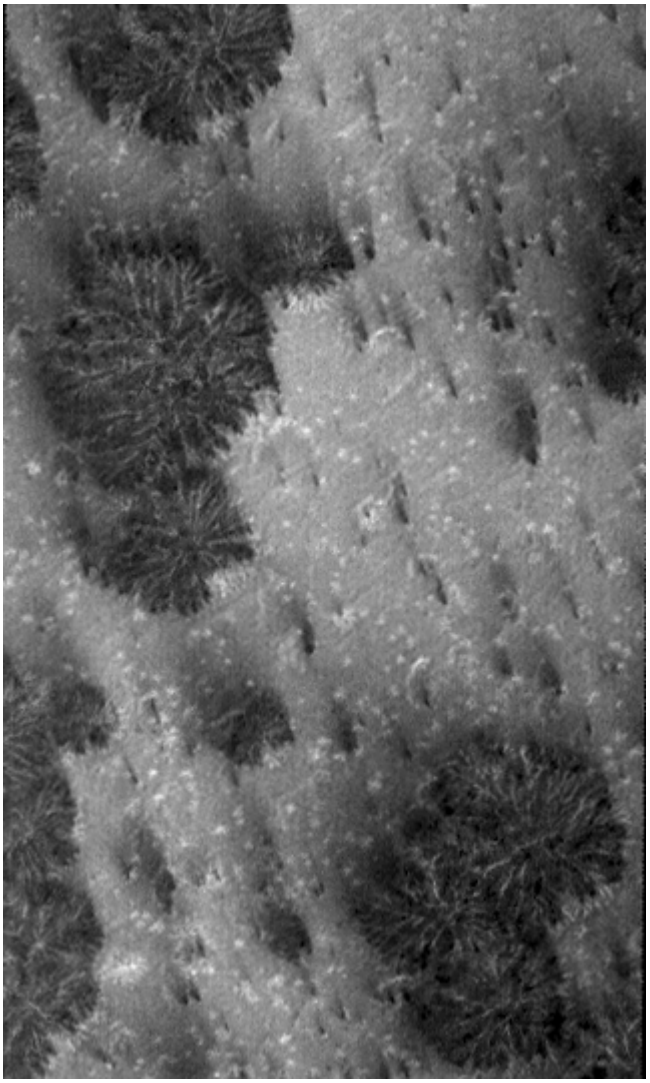
Silica

In May 2007, the Spirit rover disturbed a patch of ground with its inoperative wheel, uncovering an area extremely rich in silica (90%). The feature is reminiscent of the effect of hot spring water or steam coming into contact with volcanic rocks. Scientists consider this as evidence of a past environment that may have been favorable for microbial life, and theorize that one possible origin for the silica may have been produced by the interaction of soil with acid vapors produced by volcanic activity in the presence of water. Another possible origin could have been from water in a hot spring environment.

Geysers on Mars



Artist concept showing sand-laden jets erupt from geysers on Mars. (Published by NASA); artist: Ron Miller.



Close up of dark dune spots, likely created by cold geyser-like eruptions.

The seasonal frosting and defrosting of the southern ice cap results in the formation of spider-like radial channels carved on 1 meter thick ice by sunlight. Then, sublimed CO_2 - and probably water- increase pressure in their interior producing geyser-like eruptions of cold fluids often mixed with dark basaltic sand or mud. This process is rapid, observed happening in the space of a few days, weeks or months, a growth rate rather unusual in geology - especially for Mars.

A team of Hungarian scientists propose that the geysers' most visible features, dark dune spots and spider channels, may be colonies of photosynthetic Martian microorganisms, which over-winter beneath the ice cap, and as the sunlight returns to the pole during early spring, light penetrates the ice, the microorganisms photosynthesise and heat their immediate surroundings. A pocket of liquid water, which would normally evaporate instantly in the thin Martian atmosphere, is trapped around them by the overlying ice. As this ice layer thins, the microorganisms show through grey. When it has completely melted, they rapidly desiccate and turn black surrounded by a grey aureole. The

Hungarian scientists believe that even a complex sublimation process is insufficient to explain the formation and evolution of the dark dune spots in space and time. Since their discovery, fiction writer Arthur C. Clarke promoted these formations as deserving of study from an astrobiological perspective.

A multinational European team suggests that if liquid water is present in the spiders' channels during their annual defrost cycle, they might provide a niche where certain microscopic life forms could have retreated and adapted while sheltered from solar radiation. A British team also considers the possibility that organic matter, microbes, or even simple plants might co-exist with these inorganic formations, especially if the mechanism includes liquid water and a geothermal energy source. However, they also remark that the majority of geological structures may be accounted for without invoking any organic "life on Mars" hypothesis.

Cosmic radiation

In 1965, the Mariner 4 probe discovered that Mars had no global magnetic field that would protect the planet from potentially life-threatening cosmic radiation and solar radiation; observations made in the late 1990s by the Mars Global Surveyor confirmed this discovery. Scientists speculate that the lack of magnetic shielding helped the solar wind blow away much of Mars's atmosphere over the course of several billion years.

In 2007, it was calculated that DNA and RNA damage by cosmic radiation would limit life on Mars to depths greater than 7.5 metres below the planet's surface. Therefore, the best potential locations for discovering life on Mars may be at subsurface environments that have not been studied yet.