Astrobiology

Astrobiology is the study of the origin, evolution, distribution, and future of life in the universe. In simplest terms, it is the study of life in the universe—both on Earth and off it. It combines the search for habitable environments in the Solar System and beyond with research into the evolution and adaptability of life here on Earth. By knitting together research in astrophysics, earth science, and heliophysics as well as planetary science, astrobiology seeks to answer fundamental scientific questions about life: how it begins and evolves; what biological, planetary, and cosmic conditions must exist in order for it to take hold; and whether there is/was/can be life elsewhere in the galaxy.

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What is Astrobiology!

Astrobiology is the study of life in the Universe – where it is, how it came to be there, what it is like, and where it might be going.

As the only life we know about for sure is on Earth, a lot of astrobiology is about trying to predict where we might find life elsewhere.

Astrobiology is the study of the origin, evolution, distribution, and future of life 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 addresses the question of whether life exists beyond Earth, and how humans can detect it if it does. (The term **exobiology** is similar but more specific — it covers the search for life beyond Earth, and the effects of extraterrestrial environments on living things)

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 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.

Earth is the only place in the universe known to harbor life. However, recent advances in planetary science have changed fundamental assumptions about the

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possibility of life in the universe, raising the estimates of habitable zones around other stars and the search for extraterrestrial microbial life. The possibility of life on Mars, either currently or in the past, is an active area of research.

Overview

Astrobiology is etymologically derived from the Greek ἄστρον, *astron*, "constellation, star"; βίος, *bios*, "life"; and -λογία, *-logia*, *study*. The synonyms of Astrobiology are diverse; however, the synonyms were structured in relation to the most important sciences implied in its development: Astronomy and Biology.

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 present life on Mars. 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 (viz., University of Arizona, Penn State University, Montana State University, University of Washington, and Arizona State University), Britain (viz., The University of Glamorgan), Canada, Ireland, and Australia (viz., The University of New South Wales) now offer graduate degree programs in astrobiology. The International Astronomical Union regularly organizes International conferences through its Bioastronomy Commission.

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. 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. 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.

Methodology

Planetary habitability

When looking for life on other planets like the earth, some simplifying assumptions are useful to reduce the size of the task of the astrobiologist. One is to

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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. Carbon is the fourth most abundant element in the universe and the energy required to make or break a bond is just at an appropriate level for building molecules which are not only stable, but also reactive. The fact that carbon atoms bond readily to other carbon atoms allows for the building of arbitrarily long and complex molecules.

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.

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. (See Habitability of red dwarf systems).

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.

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Communication attempts

Communication with extraterrestrial intelligence

Research on communication with extraterrestrial intelligence (CETI) focuses on composing and deciphering messages that could theoretically be understood by another technological civilization. Communication attempts by humans have included broadcasting mathematical languages, pictorial systems such as the Arecibo message and computational approaches to detecting and deciphering 'natural' language communication. The SETI program, for example, uses both radio telescopes and optical telescopes to search for deliberate signals from extraterrestrial intelligence.

While some high-profile scientists, such as Carl Sagan, have advocated the transmission of messages, scientist Stephen Hawking has warned against it, suggesting that aliens might simply raid Earth for its resources and then move on.

Elements of Astrobiology

Astronomy

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:

$$N = R_{*} f_p . n_e . fl . f_i . f_c . L$$

where,

N is number of civilizations

- R^* is the mean rate of suitable stars (stars such as our Sun) formation in the Galaxy
- f_p the fraction of stars with planetary systems (Current evidence indicates that planetary systems may be common for stars like the Sun)
- n_e the number of planets in such systems that are ecologically suitable for the origin of life (i.e., The number of Earth-like worlds per planetary system)
- fl the fraction of such planets on which life in fact develops
- f_i the fraction of such planets on which life evolves to an intelligent form
- f_c the fraction of such worlds in which the intelligent life form invents high technology capable at least of interstellar radio communication i.e. those on which electromagnetic communications technology develops

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- ***L***, the average lifetime of such advanced 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. The problem of the formula is that it is not usable to emit hypothesis because it contains units that can never be verified. It has permitted that the applications of the formula had been related to simplistic or pseudoscientific arguments. 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

Biology and chemistry, as opposed to physics, do not admit ideological contexts: either the biological phenomena are real, or they are abstract. Biologists cannot say that a process or phenomenon, by being mathematically possible, have to exist forcibly in the real nature. For biologists, the ground of speculations is well noticeable, and biologists specify what is speculative and what is not.

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.

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. 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. According to astrophysicist Dr. Steinn Sigurdsson, "There are viable bacterial spores that have been found that are 40 million years old on Earth - and we know they're very hardened to radiation." 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 2 December 2010, it was announced that an extremophile bacterium (GFAJ-1) can be coaxed into partially substituting arsenic for phosphorus in some of its basic chemistry under laboratory conditions. Also related, on 27 June 2011, it was reported that a new E. coli bacterium was produced from an engineered DNA in which approximately 90% of its thymine was replaced with the synthetic building block 5-chlorouracil, a substance "toxic to other organisms".

Some scientists believe that these discoveries might give 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. Jupiter's moon, Europa, and Saturn's moon, Enceladus, are now considered the most likely locations for extant extraterrestrial life in the solar system.

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. In October 2011, scientists found that the cosmic dust permeating the universe contains complex organic matter ("amorphous organic solids with a mixed aromatic-aliphatic structure") that could be created naturally, and rapidly, by stars. As one of the scientists noted, "Coal and kerogen are products of life and it took a long time for them to form ... How do stars make such complicated organics under seemingly unfavorable conditions and it so rapidly?" Further, the scientist suggested that these compounds may have been related to the development of life on earth and said that, "If this is the case, life on

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Earth may have had an easier time getting started as these organics can serve as basic ingredients for life."

Astrogeology

Geology of solar terrestrial planets

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

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. If life has had a comparable impact elsewhere in the solar system, the relative abundances of chemicals key for its survival - whatever they may be - could betray its presence. Whatever extraterrestrial life may be, its tendency to chemically alter its environment might just give it away.

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 moons Titan and. Enceladus may be considered a likely candidate as well. This speculation of likely candidates of life 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

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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 and, according to NASA scientists in May 2011, "is emerging as the most habitable spot beyond Earth in the Solar System for life as we know it".

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

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Rare Earth Hypothesis by arguing the overall elements that are needed to support life on Earth are so fine-tuned that it is nearly impossible for another just like it to exist by random chance.

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. (See carbon chauvinism).

Research outcomes

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. On 5 March 2011, Richard B. Hoover, a scientist with the Marshall Space Flight Center, speculated on the finding of alleged microfossils similar to cyanobacteria in CI1 carbonaceous meteorites. However, NASA formally distanced itself from Hoover's claim. According to American astrophysicist Neil deGrasse Tyson: "At the moment, life on Earth is the only known life in the Universe, but there are compelling arguments to suggest we are not alone."

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.

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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.

Missions

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.

Many upcoming missions will, identify and measure the abundances of various minerals on Mars. Examples of minerals found on Mars so far are olivine, pyroxenes, hematite, goethite, and magnetite. Minerals are indicative of environmental conditions that existed when they formed. For example, olivine and pyroxene, two primary minerals in basalt, form when lava solidifies. Jarosite, found in sedimentary rocks by NASA's Opportunity rover on Mars, precipitates out of water. Using CheMin, scientists will be able to study further the role that water, an essential ingredient for life as we know it, played in forming minerals on Mars. For example, gypsum is a mineral that contains calcium, sulfur, and water. Anhydrite is a calcium and sulfur mineral with no water in its crystal structure. CheMin will be able to distinguish the two. Different minerals are linked to certain kinds of environments. Scientists will use CheMin to search for mineral clues indicative of a past Martian environment that might have supported life.

**[Missions will be discussed latter]*

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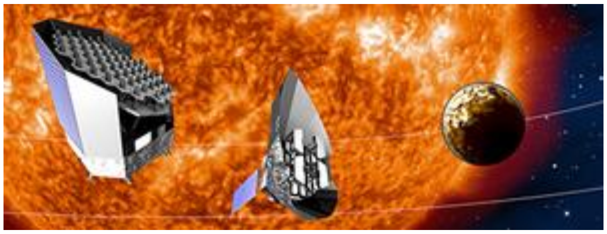
PLAnetary Transits and Oscillations of Stars (PLATO)



PLATO has been selected as a European Space Agency (ESA) mission for the 2024 launch opportunity in ESA's Cosmic Vision program. Like TESS, PLATO’s objective is to find and study a large number of extrasolar planetary systems, with emphasis on the properties of terrestrial planets in the habitable zone around Sun-like stars.

Advanced Technology Large-Aperture Space Telescope (ATLAST)

The Advanced Technology Large-Aperture Space Telescope is a concept for an 8m-16m space telescope that will allow us to perform some of the most challenging observations to answer some of our most compelling astrophysical questions, including “Is there life elsewhere in the galaxy?” ATLAST will be able to obtain spectra for tens of Earth-like planets orbiting nearby solar-like stars. It will have the sensitivity and precision to detect “biosignatures,” such as the presence of molecular oxygen and liquid water, in the atmospheres of such planets.

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The greatest leaps in our understanding of the universe typically follow the introduction of radically new observational capabilities that bring previously unobserved phenomena into view. Some, such as the unambiguous detection of life on an Earth-like planet orbiting another star, will be profound yet conceivable. Others are entirely beyond our imagination. All forever change our view of our place in the universe. ATLAST is envisioned as a flagship mission of the 2025 - 2035 period, designed to address one of the most compelling questions of our time. Is there life else where in our Galaxy? It will accomplish this by detecting "biosignatures" (such as molecular oxygen, ozone, water, and methane) in the spectra of terrestrial exoplanets.

But ATLAST is more than just a "life-finder". ATLAST will have the performance required to reveal the underlying physics that drives star formation and to trace the complex interactions between dark matter, galaxies, and the intergalactic medium. Because of the large leap in observing capabilities that ATLAST will provide, we cannot fully anticipate the diversity or direction of the investigations that will dominate its use - just as the creators of HST did not foresee its pioneering roles in characterizing the atmospheres of Jupiter-mass exoplanets or measuring the acceleration of cosmic expansion using distant supernovae. ATLAST will have the versatility to far outlast the scientific vision of current-day astronomers.

One may be surprised to learn how much science has uncovered in this area. The Kepler Space Telescope has identified more than 1,500 exoplanets–and that's only in a small portion of the sky. It's suspected that nearly every star in the universe may have a planet. Nearly 40 billion stars may have Earth-sized planets orbiting them. Within our own solar system, our understanding of the habitable conditions for life has also expanded. Some of the moons of Jupiter and Saturn may be capable of supporting living organisms. Complex organic molecules exist in outer space. On Earth, living organisms have been found to thrive in harsher environments than previously imagined. Microbial biodiversity and extremophile life are now known to be ubiquitous. That life thrives in multifarious conditions, coupled with these potentially habitable exoplanets and the detection of life-giving elements on planets, moons and asteroids, means we as

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humans must contemplate the possibility that simple or complex organisms either exist, or once existed, beyond Earth. Life of out there appears to be tenable, at least in theory.

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