NASA Facts

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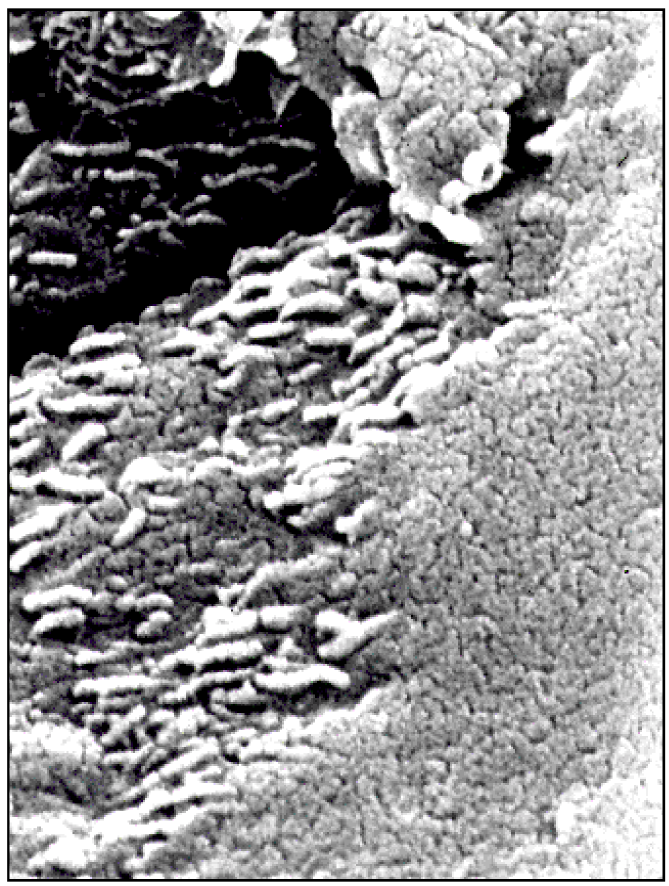
Origins of Life in the Universe

The Earth today is rich in life. Its diversity is so great that we have not even completed a census. There may be 5 to 30 million species, yet we have named fewer than 2 million; fewer still have been studied in detail. Everything on which human survival depends is tied to diversity of life, though we are still learning exactly how. Even the specific composition of our atmosphere is controlled by biological activity. Yet, in spite of our ignorance of the ecological roles played by many living organisms, human activity is driving species to extinction at an ever-increasing rate.

The exploration of space offers a new perspective from which to understand life. We see the Earth as a tiny and fragile oasis in the hostile environment of space. We develop a renewed appreciation for the beauty and value of life, and we wonder anew about the origins of life. How did such an amazing array of life begin and evolve on our planet? Has a similar process occurred on other planets, either in our solar system or beyond? If so, might we someday establish that life did exist on planets around other stars? We are just beginning the search for answers to these fundamental questions that have been pondered by scientists and philosophers for thousands of years.



Electron micrograph of an ancient Martian meteorite showing possible nanometer-size bacteria (less than 1/100th the width of a human hair). The rock probably formed on Mars about 4.5 billion years ago and is the only Martian meteorite believed to be older than 1.3 billion years. (Currently, there are only 12 known meteorites from Mars.)

Life: A Product of Stars

The essential raw materials, or building blocks, of life are the *biogenic elements*—hydrogen, carbon, nitrogen, oxygen, sulfur, and phosphorus — from which all living things are made. To find the origins of the biogenic elements, we must go all the way back to the *Big Bang*, the beginning of the universe some 9 to 14 billion years ago. Only the lightest elements, hydrogen and helium, were produced during the Big Bang. These remain, by far, the most common elements in the universe today. Although hydrogen, an ingredient of water, is essential to life, other elements had to be created before life could exist.

Carbon, nitrogen, oxygen, and all the other heavier elements are produced by stars. Stars are born when clouds of interstellar gas contract and begin a fusion reaction, "burning" the hydrogen at its core at a prodigious rate, which will soon exhaust its supply. Gravity will then collapse its core to ever higher temperatures, allowing the star to fuse helium into carbon, carbon into oxygen, and so on. Through this process, called *nucleosynthesis*, the biogenic elements are formed.

The final death of a massive star occurs in a titanic explosion, called a supernova, during which its products (including its biogenic elements) are returned to interstellar space. There they are recycled into future generations of stars. Our solar system was made from such recycled material. The Earth, with all its living organisms, is built from elements created inside massive stars that died before our solar system was born. Truly, we are the products of stars.

Life in Our Solar System

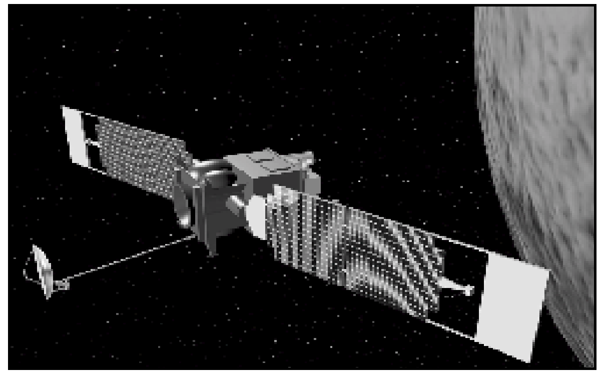
Although science fiction is filled with tales of alien civilizations in places as close as Mars, planetary probes and other observations have found no evidence of alien intelligence in our solar system. In retrospect, this is not surprising, considering that life existed on Earth only as single-celled, microscopic organisms for most of its history. Thus the question remains: Is there the possibility of life, past or present, elsewhere in our solar system?

Life on Earth has been found within the deep subsurface, in hydrothermal vents on the ocean floor at temperatures as high as 118˚ C (244˚ F), in permafrost that has remained frozen for millions of years, beneath perennial ice covers, and inside the rocks of cold deserts. Where there has been water, there has been life. Thus, on other planets, the search for the evidence of life requires understanding the history of water and operationally becomes the search for liquid water, both past or present.

In the case of Venus and Mars, both planets had beginnings similar to Earth. Life evolved quickly on early Earth and perhaps it did likewise on Venus or Mars. Today, however, a runaway greenhouse effect bakes Venus at 450˚ C (842˚ F)—far too hot for life as we know it. Mars, on the other hand, is considered a better candidate for the development of life (see box). In 1976, two Viking spacecraft landed on Mars, but found no conclusive evidence of life. However, the spacecraft only scratched the surface of a planet that in the past, had liquid water on the surface, and today, may have liquid water in the deep subsurface.

The atmospheres of the giant planets (Jupiter, Saturn, Uranus, Neptune) contain many organic molecules, but water is only found in clouds, and their turbulence makes them unlikely candidates for the development of life. Organic chemicals also are found on Saturn's moon Titan (which will be explored in detail by NASA's upcoming Cassini mission), but its surface appears too cold for liquid water.

The large moons in the outer solar system, like Jupiter's moons Europa, Ganymede, and Callisto (which are being studied by NASA's Galileo spacecraft), and Neptune's moon Triton are frozen, airless worlds that could not support life on their surfaces, but may have complex interior chemistries. Europa may have liquid water deep beneath its frozen surface, perhaps supporting a hydrothermal system capable of originating and sustaining life, analogous to the deep-sea vent communities found at the rift zones in our oceans. Voyager and recent Galileo images show a fractured surface on Europa, not dissimilar to ice-flows seen over polar oceans on Earth. A Galileo fly-by in December 1996 could refine our assessment of the possibility of a subsurface ocean on Europa.



Artist's concept of the Mars Pathfinder lander and rover deployed on the Martian surface. The rover has a boom extended that is measuring the elements of a nearby rock as the lander instruments survey the surrounding area. (left)
Artist's concept of the Mars Global Surveyor as it explores the Martian terrain. (right)

During the time that life began on Earth (at least 3.5 billion years ago), Mars also had water flowing across its surface. But how far along the path of evolution did Mars progress? Did complex chemistry progress to life? Recent evidence from a Martian meteorite found in Antarctica suggests that early Mars might have had life. This finding, however, is controversial and will only be resolved with further studies of ancient Mars. Fortunately, there is an expanse of ancient terrain on Mars, promising ample samples for studying the early history of this planet. In exploring Mars, we may find evidence of liquid water, of early chemical evolution, or even of life. In fact, Mars may prove to contain the best evidence of life's beginning in our solar system.

Because the search for evidence of life may require finding a specific sample with the "right stuff," the exploration of Mars is best viewed as a series of missions that narrow the focus to the most promising sites for detailed analysis. With increasing resolution, the mission series will progress from global reconnaissance, to high-resolution imaging of minerals characteristic of water activity, to landed mission studies of rocks capable of preserving the signatures of life. The investigation will conclude with a series of mission that will bring the best samples back to Earth for detailed analysis.

The next steps in this series are the Mars Global Surveyor, Mars Pathfinder, and the joint Russia/US Mars '96 and Mars '98 missions. Mars Global Surveyor (November 1996) will orbit Mars for at least 2 years studying the chemical composition of its surface and its geological history. The Mars Pathfinder (launches in December 1996) will deploy a lander and small rover on the surface of Mars to explore its terrain. Mars '96 (late 1996) and will sample the chemistry of Martian soil from two sites on the Mars surface. Mars '98 (late 1998) will have an orbiter and lander to study the characteristics of the Mars southern polar region.

Life Elsewhere in the Universe

The Sun is just one of more than a hundred billion stars in the Milky Way, and our galaxy is just one of some 40 to 50 billion galaxies in the universe. A vast number of stars are similar to our Sun in size and brightness, and many are as old or older.

Although to date scientists have only detected a small number of planets around nearby stars, these findings suggest that it is likely that many stars are orbited by planets.

Among the most intriguing of all questions are whether any of these planets support life (either past or present) and whether any of that life evolved to develop a civilization. If the answer is yes, then we are not alone in the cosmos.

The Search for Origins Continues

NASA is developing a plan for a series of missions that will have as their ultimate goal the imaging of an Earth-sized planet around a nearby star within the next 25 to 50 years. While a small number of planets have now been identified around stars beyond our own solar system, all of these have been substantially larger (and thereby easier to detect).

The Origins Program will be the core scientific and technological activity of NASA to understand the processes which led to the universe we see today, namely, to understand the birth and early evolution of normal galaxies, the formation of stars, the existence of planetary systems, and the search for planets, like the Earth, which might harbor life.

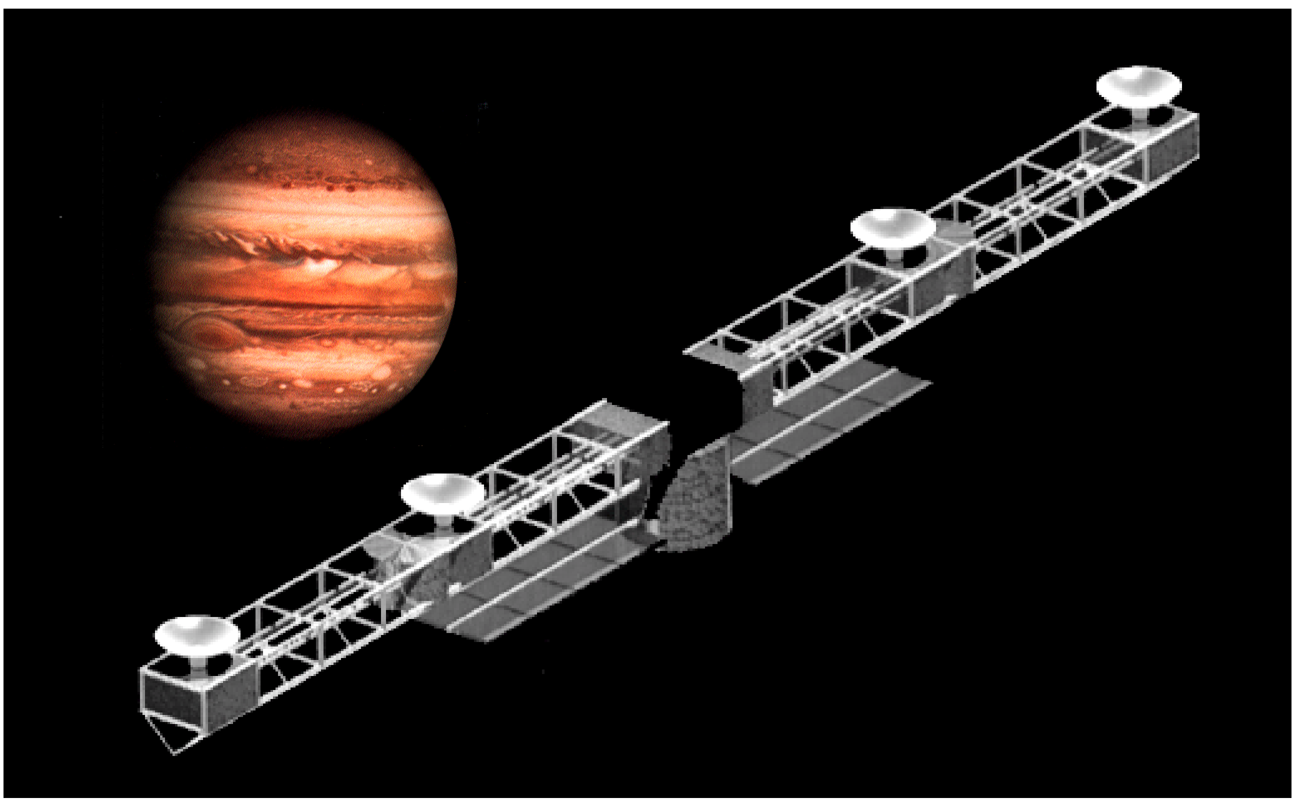
The primary goal of the Origins Program is to answer the following fundamental questions:

- Where do galaxies, stars and planets come from?
- Are there worlds like the Earth around nearby stars? If so, are they habitable and is life present there?
- What is the origin of the universe?

Central to this program will be the development of a new generation of extremely powerful space facilities, to follow the Great Observatories (the Hubble Space Telescope and the Compton Gamma Ray Observatory are operating on orbit, the Advanced X-ray Astrophysics Facility is scheduled to launch in 1998, and the Space Infrared Telescope is being studied by NASA as a possible launch early in the next decade). These next generation missions will have significantly greater sensitivity and be able to make better measurements, but must also be significantly less costly than the current class of major space facilities.

NASA's strategy for this program focuses on development and infusion of new technologies which will allow missions which are both scientifically compelling and affordable, and implementing each mission so that it provides a major leap in our observational capabilities.

Until then, we can only look at the night sky and wonder whether we are alone in the vastness of space and whether Earth-like planets orbit around nearby stars.



Artist's concept of one possible design for a large planet-finding mission. It is shown near Jupiter, where it would be most effective, away from the warmer parts of the solar system and beyond the cloud of dust inside Jupiter's orbit (not drawn to scale).