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Exobiology: The NASA Program

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Exobiology is an interdisciplinary program of scientific research supported by the Life Sciences Division of NASA. As its goal, the program seeks to increase knowledge of the origin, evolution, and distribution of life in the universe: answers are sought as to how the development of the solar system led to a habitable planet, how life originated on Earth, what factors influenced the course of biological evolution, and where else life may be found in the universe. These questions have broad scientific and cultural significance by addressing the possibility that life is unique to Earth while investigating prospects for its existence and detection elsewhere. A general theory for the natural origin and evolution of living systems within the context of the origin of the universe may eventually arise from knowledge gained in the systematic search for answers to these age-old questions.

NASA is chartered to promote "the expansion of human knowledge of phenomena in ... space" (National Aeronautics and Space Act of 1958). The rationale for conducting the Exobiology Program has been, and continues to be, firmly rooted in the agency's charter. Our understanding of biology and the natural history of life on Earth strongly indicates that biological evolution is subject to the vicissitudes of planetary and solar system evolution and that life could well arise and evolve on suitable planets. For these reasons, unparalleled opportunities to contribute to the state of knowledge of the biological sciences are embodied within the missions and projects associated with NASA's exploration of space.

At the scientific core of the Exobiology Program lie issues concerning the natural history of life in the universe, all of which can be addressed most fruitfully in the context of evolution. In the galactic, cosmic, solar system, planetary, or environmental sense, "evolution" refers to the course of change over time as a consequence of the changing thermodynamic state of the universe. It is within this milieu that life arose and evolved in concert with the physiochemical universe. From a biological point of view, evolutionary change in living systems is wrought by physical, environmental, and biological events: mutation, reproduction, and natural selection. Life, then, may be viewed as a unique product of countless changes in the form of primordial matter—ultimately changes wrought by the processes of astrophysical, cosmochemical, geological, and biological evolution, which are all aspects of the evolution of the universe. Therefore, the historical relationship between the two courses of evolution and the history of processes involved in the dynamics of that relationship constitute the unifying conceptual framework of the Exobiology Program.

Recognition of the concept of evolutionary interplay has led to a focused program of scientific research on how the natural history of that interplay took place. The Solar System Exploration Committee (SSEC) of the NASA Advisory Council has articulated several goals as NASA's mission capabilities expand and diversify. Three of the committee's stated goals are

1. To determine the origin, evolution, and present state of the solar system.

2. To understand Earth through comparative planetology studies.

3. To understand the relationship between the chemical and physical evolution of the solar system and the appearance of life.

The thinking of the SSEC and other advisory committees, along with the present state of space life sciences and NASA's schedule of missions and projects for the upcoming years, have been factored into the formulation of goals and objectives for the Exobiology Program. As stated before, the overarching goal of the program is to understand the origin, evolution, and distribution of life in the universe. To do this, the Exobiology Program seeks to provide a critical framework and some key research to allow NASA to bear the combined talents and capabilities of the agency and the scientific community, and the unique opportunities afforded by space exploration. To provide structure and direction to the quest for answers, the Exobiology Program has instituted a comprehensive research program divided into four program elements which are being implemented at several of NASA's research centers and in the university community. These program elements correspond to the four major epochs in the evolution of living systems:

1. Cosmic evolution of the biogenic compounds;

2. Prebiotic evolution;

3. Origin and early evolution of life; and

4. Evolution of advanced life.

The overall research program is designed to trace the pathways leading from the origin of the universe through the major epochs in the story of life.

Cosmic Evolution of the Biogenic Compounds

The first epoch, the cosmic evolution of the biogenic compounds, encompasses galactic time and distance scales; it begins with the nucleosynthesis of the biogenic elements, which make up the bulk of all living materials, and ends with the transformation of their compounds into planetesimals, the building blocks of planets. Within these bounds are included relevant phenomena in stars, interstellar clouds, presolar nebulae, and the primitive objects in the solar system. These phenomena precede the first stage of planetary evolution: this epoch of cosmic evolution sets the stage for the formation and evolution of the solar system and its planetary bodies.

The goal of this program element is to determine the history of the biogenic elements (C, H, N, O, P, and S) from their birth in stars to their incorporation into planetary bodies.

NASA's development of astronomical telescopes for use in space, its program for the study of pristine objects like comets and asteroids (and materials derived from them) using ground-based laboratories and spacecraft, all provide a framework of opportunities to enhance our knowledge of the events in this epoch. In the late 1990s, research facilities on Space Station Freedom will allow exobiology experiments to be conducted under microgravity conditions. Of particular interest to exobiologists is the Cosmic Dust Collection Facility, planned as an attached payload, and the Gas-Grain Simulation Facility, planned for use within the pressurized volume of Space Station Freedom.

Cosmic Evolution of the Biogenic Elements

Supporting NASA Missions/Projects

- Past and Present
  - Kuiper Airborne Observatory
  - International Halley Watch
  - ER-2 IDP Collection Flights
  - Ground-Based Radio Astronomy
  - Meteorite Collection Programs
  - Infrared Telescope Facility
  - Ames Vertical Gas Gun
- Future
  - Comet Rendezvous Asteroid Flyby
  - SOFIA
  - SIRTF
  - SSF Cosmic Dust Collector
  - SSF Gas-Grain Simulation Facility
  - Comet Nucleus Sample Return

Figure 15-1.

Investigations and activities conducted within this program element continue to increase our understanding of this epoch (fig. 15-1). All of the biogenic elements have now been detected in space. Laboratory data compared with astronomical observations of interstellar clouds have revealed the presence of molecular ices in the protostellar environment and these ices have been found to contain such biologically significant materials as water, ammonia, carbon monoxide, alcohols, nitrates, aldehydes, and other organic molecules. The implication is that the chemical constituents needed for the development of life are available throughout the universe.

Organics have also been detected in comets such as Halley. Comets are objects believed to have been preserved intact, below their surfaces, since the first epochs of solar system formation. Analysis of the Murchison meteorite revealed the presence of amino acids with a deuterium/hydrogen ratio similar to that in interstellar space, providing a link in the incorporation of interstellar materials into our solar system. Similarly, diamond residue from the Allende CV3 meteorite revealed information on temperatures and pressures encountered in the presolar nebula and affecting the formation of the biogenic elements. Thus, it is becoming apparent that chemistry in space may be linked directly to the chemistry we see on Earth.

Prebiotic Evolution

The second epoch, prebiotic evolution, begins with the formation of planets and ends with the emergence of living organisms from the prebiotic milieu. The research in this area includes studies of two kinds of processes: planetary and molecular. Planetary processes occur on global or local scales as a consequence of the development of planets and are responsible for setting the physical and chemical conditions of the planets' various environments wherein living systems may arise. Molecular processes may also occur on macro- or micro-environmental scales, but they comprise the chemical and physical mechanisms by which the structures and functions that are attributable to primitive life forms develop and assemble in response to energy sources. This differentiation has been made for purposes of the programmatic organization; research on the existence of a continuum between the two—and their essential interdependence— is acknowledged.

The goal of this program element is to understand the pathways and processes leading from the origin of the planet to the origin of life. This involves the investigation of the planetary and molecular processes that set the physical and chemical conditions within which chemical evolution occurred and living systems arose.

From the standpoint of the origin of life, prebiotic evolution is the most important epoch and the one about which the least is known, primarily because of a lack of an extant fossil geological record on Earth and because of the immaturity of theories dealing with origins of both planets and biological systems. This area continues to be targeted for major emphasis (fig. 15-2). NASA's capabilities are uniquely suited to enhancing present knowledge of prebiotic evolution, insofar as the agency's program of planetary exploration will allow important gaps in the geological record to be filled by studies of other planets and small bodies in the solar system.

Prebiotic Evolution

Supporting Missions/Projects

- Past and Present
  - Apollo
  - Viking
  - Pioneer
  - Mariner
  - Meteorite Collection Programs (USARP)
  - Deep-Sea Vent Explorations (NOAA)
- Future
  - Mars Observer
  - Titan-Cassini Mission
  - Mars Rover/Sample Return
  - Hubble Space Telescope
  - Astrometric Telescope/CIT

Figure 15-2.

The studies conducted should explore a continuum of planetary possibilities, including bodies devoid of organic chemicals, those conceivably undergoing (or having undergone) organic chemical evolution, and those possibly harboring life, extant or extinct. Carefully selected sites for exploration may reveal the remnants of chemical precursors to living systems and allow examination of cases where planetary evolution may have diverged from the path that led to the origin of life on Earth. Lifeless planets, meanwhile, provide examples of environments where prebiotic chemical evolution or subsequent biological evolution never occurred or ended. The search for other planetary systems is an integral element of these studies and extends the search for life and potentially habitable environments beyond the solar system.

Evolution of Early Life

The third and fourth epochs encompass biological evolution, beginning with the emergence of living systems from the prebiotic planetary environment and carrying through to the appearance of intelligence in advanced organisms. The goal of research into the early evolution of life is to determine the nature of the most primitive organisms, the environment in which they evolved, and the way in which they influenced that environment. Research in the early evolution of life focuses on deciphering the records of biological evolution preserved in rocks and in contemporary organisms and ecosystems, with a view toward understanding how the evolution of early microbial life was influenced by changes in surface environmental conditions on early Earth. A further useful division of this research is made into studies of the geological record and the biological record, insofar as different strategies, methods, and materials are employed in each. Figure 15-3 illustrates former and planned future missions supporting this area of research.

Evolution of Early Life

Supporting Missions/Projects

- Former and Current
  - Viking Missions
  - Deep-Sea Vent Explorations (NOAA)
- Future
  - Mars Rover/Sample Return
  - EOS (Baseline Studies)
  - VLBI Studies of Extrasolar System Planets

Figure 15-3.

A major question for exobiologists in the 1990s and beyond is that of the planets and life. Fossils 3.5 billion years old have been located in the Warawoona Group in Western Australia. These are the earliest records of life found thus far. Their discovery has pushed back temporal estimates for the origin of life millions of years, to a time when the environments of early Earth and early Mars may have been much more similar than they are now.

Indications are that both planets may have been suitable for development of life during this remote epoch. Since we know that life evolved on our own planet, Earth, the question arises, Did life evolve on the planet Mars during this more clement period, and if not, why not?

Current exobiological research using the lakes in the dry valleys of Antarctica as analogs of possible Martian paleolakes is providing insight into ways to conduct the future search for remnants of life on Mars. Additionally, studies of endolithic organisms found in these dry valley regions may offer clues for future searches of bio-markers of past life on the arid red planet.

Evolution of Advanced Life

The research associated with the study of the evolution of advanced life seeks to determine the extrinsic factors influencing the development of advanced life and its potential distribution. This research includes an evaluation of the effect of extraterrestrial influences on the appearance and evolution of multicellular life, conducted by (1) tracing the effects of major changes in the Earth's environment on the evolution of complex life, especially during mass extinction events; (2) determining the effects of global events and events originating in space on the production of environmental changes that affected the evolution of advanced life; and (3) by searching for evidence of advanced life elsewhere in the galaxy. Planned future missions, as well as previous missions, supporting the study of evolution of advanced life are listed in figure 15-4.

Evolution of Advanced Life

Supporting Missions/Projects

- Former and Current
  - Apollo Missions
  - Viking Missions
  - Pioneer Missions
  - Mariner Missions
- Future
  - SETI Microwave Observing Project
  - The Great Observatories

Figure 15-4.

Preparation for Future Missions

It is hoped that during the next 10 years the Exobiology Program will fly experiments on each of the following missions described, as the opportunities arise.

(1) Mars Observer. A mission that will determine the global elemental and mineralogical character of the surface of the planet Mars.

(2) The Search for Extraterrestrial Intelligence (SETI). A multichannel receiver and spectrum analyzer have been developed and tested. The next step is a systematic search using existing ground-based radio telescopes.

(3) Earth Orbiting Telescopes. An active effort is ongoing in the astrophysical community to develop and fly Earth-orbiting platforms capable of observations in wavelength intervals and at resolutions unattainable from the surface of Earth. Especially noteworthy opportunities include the Hubble Space Telescope and the future Space Infrared Telescope Facility (SIRTF). Astronomical observations of key interest to exobiology include: the detection of interstellar organic molecules, the spectroscopic characterization of the carbonaceous components of interstellar and circumstellar dust, and the detection of protoplanetary nebula and planetary systems.

(4) Comet Rendezvous-Asteroid Flyby (CRAF). This mission has been recently canceled. If resurrected, it will make a close rendezvous with a comet nucleus. It will make measurements to determine the nature and characteristics of a comet nucleus, thereby providing exobiologists with much needed information of chemical evolution in the outer solar system.

(5) Cassini. Its objective is to characterize the composition and structure of Titan's atmosphere and of the Saturnian system. There is a considerable amount of methane on Titan, and Voyager detected at least nine organic compounds more complex than methane. The atmospheric haze observed is believed to be composed of solid organic material. It seems certain that Titan will reveal much about the organic chemistry that can occur in an abiological setting. Current plans for exobiology involvement on a Titan probe center on analyses of the organic compounds in the gas phase and in the solid aerosol material.

(6) Cosmic Dust Collection Facility. Designed for Space Station Freedom, this device will enable the nondestructive capture of high-speed extraterrestrial particles in the micrometer size range. As particles are captured, a complete description of their state of motion will be obtained. This will allow for determination of their point of origin and hence their astrogeophysical source. Capture methods, such as the use of underdense collection media, also offer near-term capabilities that can be exploited on spacecraft before Space Station Freedom is operational. Grains that originate from known comets and grains that are interstellar in origin would be of particular importance.

(7) Space Station Freedom Gas-Grain Simulation Facility. Space Station Freedom will provide unique opportunities to study physical and chemical processes in microgravity. Simulation studies designed to investigate the circumstellar, interstellar and protosolar nebular environments and processes can provide new information on topics such as grain condensation, comet mantle formation, grain-grain and gas-grain interactions involving the biogenic elements and compounds.

(8) Mars Environmental Survey Network Mission (MESUR). This mission set will deploy a series of penetrators and/or small stations to several sites on the surface of Mars. Capabilities envisioned include descent imaging, seismometry, and geochemical analysis of surface and near-surface materials.

(9) Mars Rover/Sample Return. This mission will involve detailed study of specific sites on Mars. (Sites will probably be selected on the basis of data returned by the Mars Observer and Network Missions.) Anticipated here are

opportunities to study the history of the biogenic elements, principally water, on Mars and to conduct a more intensive search for traces of past organic activity and remnants of past life.

Mission opportunities of relevance to exobiology will continue to arise in the early 21st century as the space program matures and its capabilities expand. These include: Comet Sample Return, Asteroid Sample Return, Large Deployable Reflector (an Earth-orbiting telescope), Pluto flyby, Neptune orbiter, Lunar Base, and Mars Base.

Emphasis will most likely be placed on the sample return missions to Mars and to a comet, the two augmented missions recommended by the SSEC. These targets are accessible with technology available in the near future; collecting devices and associated hardware will be able to survive and function on the surfaces of the bodies and previous missions will have provided enough information about the targets to allow detailed planning. Both missions are of prime importance to the Exobiology Program.

Summary

The goal of the Exobiology Program is to understand the origin, evolution, and distribution of life throughout the universe. Because of recent advances in diverse contributing fields of science, the Exobiology Program is now ready to advance the theory that life is a natural consequence of the physical and chemical processes that comprise the evolution of the cosmos, and to embark upon a scientifically rigorous course of action to test this theory. It is felt that by synthesizing the results from the studies described, it should be possible to generate a set of rules that describes the path of life from nucleosynthesis of biogenic elements in stars through evolution of planetary systems to the origin of life and evolution of intelligent life.

Additional Reading

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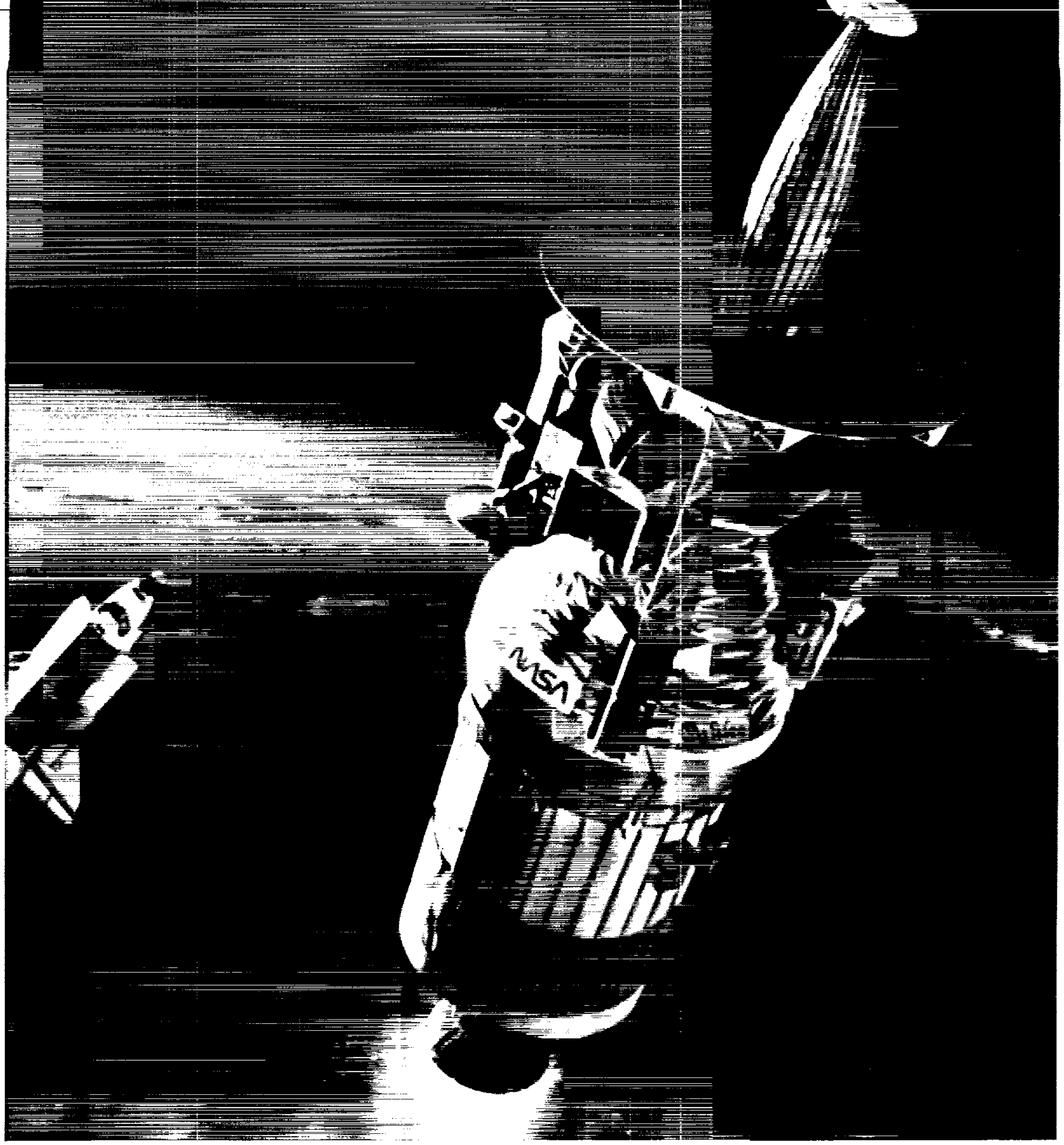
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