61st International Astronautical Congress
27 September-1 October, Prague, Czech Republic

IAC-10.A1.5.1

50 Years of Exobiology and Astrobiology: Science Accomplishments, Public Perceptions

Session A1, Space Life Sciences Symposium
"Astrobiology and Exploration"
30 September, 10:15 am, Small Theatre

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Introduction

This year marks the 50th anniversary of the U.S. National Aeronautics and Space Administration's research program in exobiology and astrobiology. Astrobiology is now a household word, and it seems to be a part of the conversation wherever and whenever space science and exploration is on the agenda.

NASA established an Exobiology Program in 1960, to study the potential for life beyond Earth. Over the years, the Exobiology Program expanded to encompass studies of evolutionary biology, the origin and evolution of prebiotic elements and compounds in the universe, the search for extrasolar planets, and the future of life in the universe. By the mid-1990s, NASA's Exobiology Program had evolved and grown into an expansively multidisciplinary Astrobiology Program, and today, astrobiology is an increasing focus of planetary exploration missions, especially missions to Mars and the Jupiter and Saturn systems.

This paper will review the historical origins and contributions of exobiology and astrobiology, global development of the field, and primary research questions and findings in the field, including an ongoing concern for social, philosophical, and ethical issues relating to this area of research. Topics to be covered include the origin and history of NASA's Exobiology Program; the tradition of cutting-edge research in exobiology and astrobiology; the rise and fall and rise of scientific and public interest in the search for evidence of extraterrestrial life; important early contributions of NASA's exobiology research program; and current trends and new ideas in exobiology and astrobiology research, which is now a truly global endeavor, with research ranging from Earth's two poles to the outer solar system, extrasolar planetary systems, and the interstellar environment. In particular, this paper will address 50 years of public interest in and opinions about scientific studies of the origin, evolution, distribution, and future of life in the universe and consider current challenges and opportunities in communication about astrobiology.

What is astrobiology?

Astrobiology is the study of the origin, evolution, distribution, and future of life in the universe. It is a multidisciplinary field of research, drawing on knowledge and expertise in astronomy, biology (particularly microbiology and evolutionary biology), chemistry, earth and planetary sciences, physics and many hybrid or sub-disciplines. Astrobiology also involves studies in the humanities (primarily philosophy and theology) and social sciences.

Astrobiology encompasses the search for evidence of prebiotic chemistry, signs of past or present life on Mars and other bodies in our solar system, habitable environments in our solar system, and habitable planets outside our solar system. It also includes laboratory and field research focused on understanding the origins and early evolution of life on Earth, and of Earth itself, and studies of the potential for life to adapt to challenges on Earth and in space.

The term “astrobiology” was officially established in the lexicon of space science in the mid-1990s when NASA established its Astrobiology Program. But the science encompassed by the field of astrobiology has a long history. Scientific study of the origin, evolution, and distribution of life in the universe was well under way before NASA was established in 1958. The theory of cosmic evolution that underlies the study of the origin, evolution and distribution of life in the universe predates the 20^{th} century, the theory of chemical evolution leading to the origin of life dates back to the 1920s, and laboratory synthesis of amino acids under simulated early-Earth conditions first took place in 1953.

The idea that life might exist beyond Earth is thousands of years old, and the idea of searching for scientific evidence of extraterrestrial life is as old as the Space Age. As soon as it became clear that nations would start launching spacecraft to explore our solar system, scientists started talking about how they might take advantage of access to space to look for evidence of ET life and how this endeavor related to ongoing research into the origin and evolution of life on Earth.

One of those scientists was Joshua Lederberg. As early as 1957, Lederberg was communicating with colleagues in the scientific community about the possibility of searching for evidence of ET life. Lederberg quickly became a key player in the field. He is widely credited with coining the term “exobiology,” and he was one of the first beneficiaries of NASA’s Exobiology Program, receiving funding to develop a device for conducting biochemical analyses of soil samples. He served as a member of the Biology Team for NASA’s Viking mission to Mars.

In 1958, the year that NASA was formed, Lederberg, at age 33, won the Nobel Prize in Physiology or Medicine. Also in 1958, Science published an article coauthored by Lederberg making the case for studying lunar dust as a “record of cosmic history” that might yield information about “the biochemical origins of life.”

In 1960, Lederberg presented a paper on exobiology at a meeting of the international Committee on Space Research (COSPAR). Later that year, the journal Science published an article by Lederberg, at that point a professor of genetics at Stanford University, entitled “Exobiology: experimental approaches to life beyond Earth,” based on his COSPAR talk.

“Exobiology is no more fantastic than the realization of space travel itself,” Lederberg declared, “and we have a grave responsibility to explore its implications for science and for human welfare with our best scientific insights and knowledge.” The article was later published in a National Academy of Sciences report on "Science in Space." Thus, one of the world's leading scientific journals and the leading U.S. arbiter of scientific legitimacy validated exobiology as science.

Thanks to Lederberg and his colleagues, by the time NASA established its program, exobiology had a well articulated rationale, one that embedded this line of research firmly in the context of the broader scientific enterprise.

At the same time, some scientists espoused a minority view that exobiology was not "real science." In 1964, for example, another solidly credentialed scientist, George Gaylord Simpson, then Alexander Agassiz professor of vertebrate paleontology at Harvard University, disagreed with Lederberg in the pages of Science, responding to ongoing discussions in the scientific community "of the view that life exists not only elsewhere but even everywhere in the cosmos." Simpson argued, "We are now spending billions of dollars a year and an enormously disproportionate part of our badly needed engineering and scientific manpower on space programs. The prospective discovery of extraterrestrial life is advanced as one of the major reasons, or excuses, for this. Let us face the fact that this is a gamble at the most adverse odds in history."

NASA funded its first exobiology investigation in 1959 – a life-detection experiment intended for launch on the Viking mission to Mars. While this investigation ultimately did not fly on the mission, it did help to kick-start exobiology at NASA. In 1960, the agency established an exobiology research and analysis program, whose early managers adopted an approach to advancing this field of study by funding forward-thinking, boundary-bending, multidisciplinary research projects that the U.S. National Science Foundation and other government research organizations tended to judge as too risky. Later managers of the program maintained this approach, which continues today.

NASA's Viking missions to Mars, launched in 1976, included three exobiology experiments designed to look for evidence of life on that planet. The scientific consensus was, and still is, that those experiments did not yield any evidence of biological activity on Mars. Nonetheless, Mars is a primary focus of astrobiology today….

By the 1980s NASA expanded its exobiology program to encompass studies of evolutionary biology. In the 1990s, NASA again expanded the breadth and depth of this program, broadening the boundaries of "exobiology" to establish "astrobiology" as a program encompassing studies of chemical evolution in interstellar space, the formation and evolution of planets, and the natural history of Earth in addition to exobiology and evolutionary biology.

Astrobiology today

NASA's Astrobiology Program today addresses three fundamental questions: How does life begin and evolve? Is there life beyond Earth and, if so, how can we detect it? What is the future of life on Earth and in the universe? In striving to answer these questions and improve understanding of biological, planetary and cosmic phenomena and relationships among them, experts in astronomy and astrophysics, Earth and planetary sciences, microbiology and evolutionary biology, cosmochemistry, and other relevant disciplines are participating in astrobiology research and helping to advance the enterprise of space exploration.

The Astrobiology Program is a research and analysis program of the Planetary Science Division in NASA's Science Mission Directorate (SMD). As an R&A program, it supports research and technology development that contribute to planetary exploration missions. The U.S. National Research Council, in its 2006 assessment of balance in NASA's science programs, highlighted the key role that Astrobiology plays in NASA's science portfolio.

Missions described in the NRC's last decadal survey of planetary exploration "are all key missions in astrobiology, whether they are labeled as such or not. And issues and missions related to astrobiology represent one of the key areas of interest identified in the astronomy and astrophysics communities." In the current NRC decadal survey of planetary exploration, astrobiology is receiving prominent attention.

The NASA Astrobiology Program now has several elements: Exobiology and Evolutionary Biology, a basic grants program; Astrobiology Science and Technology Instrument Development, which supports research and development on mission instruments and concepts; Astrobiology Science and Technology for Exploring Planets, which funds field expeditions to conduct research and test systems for planetary missions; and an Astrobiology Small Payloads program.

The Astrobiology Program is guided by a "roadmap" of goals and objectives that is generated by the science community and updated every 5 years. The work of the Program is closely coordinated with NASA's Mars Exploration Program and the agency's Planetary Protection Officer.

The science of astrobiology

The study of the origins and evolution of life on Earth, the origin and evolution of Earth itself and its sister planets, the origins and evolution of life in the universe, and the origins and evolution of the universe itself are intricately intertwined. In their research on these topics, astrobiologists have learned that life as we know it – that is, carbon-based cellular life – can survive in virtually all terrestrial environmental conditions, from nuclear radiation to permafrost and Earth's deep, sunless subsurface.

At the same time that studies of the origin, evolution, and distribution of life on Earth are revealing that life is highly resilient, these same lines of research are helping to reveal how life and its environment are deeply interdependent, improving understanding of life on Earth and prospects for life elsewhere, and contributing to understanding of global climate history and evolution.

Today, the possibility of extraterrestrial life is a serious scientific question. Recent research findings that are relevant to this key question in astrobiology include evidence of past and perhaps even present liquid water on Mars, the existence of an ice-covered liquid water ocean on Europa, the discovery of hundreds of extrasolar planets, plumes of water-ice particles observed erupting from Saturn's moon Enceladus, the possibility of liquid water beneath the surface of Titan, and identification of new forms of microbial life in an ever-widening range of extreme Earth environments. Mars is now considered the best – though not the only – place to look for evidence of extraterrestrial life, past or present, in our solar system.

Astrobiologists are identifying "biomarkers" – for instance, the presence of certain gases at certain levels in a planetary atmosphere – that would be signals for the possible presence of extraterrestrial life as we know it. Earth life is carbon-based, requires water as a solvent, and needs energy (solar, geothermal, or chemical). At the same time, they are also attempting to define biomarkers for extraterrestrial life as we don't know it – non-carbon-based, using solvents other than water, involving different energy sources and chemical reactions.

In the 21st century, astrobiology is a focus of a growing number of NASA missions. While the search for extrasolar planets, including habitable planets, is a major element of NASA's program in astronomy and astrophysics, the Astrobiology Program sponsors efforts to identify and characterize habitable planetary environments. In 2009, NASA launched the Kepler mission, which 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, and astrobiologists are involved in this mission.

In 1996, a NASA-sponsored team of scientists claimed that they had found what they believed to be fossil evidence of ancient microbial life in a martian meteorite (ALH 84001). While this team is continuing its analyses, the scientific consensus today is that while fossil evidence of past microbial life on Mars may very well exist, analysis of ALH 84001 or any other martian meteorite fund on Earth has not yet yielded any evidence of biology on Mars. Meanwhile, planetary missions such as Mars Odyssey, the Mars Reconnaissance Orbiter, the Mars Exploration Rovers, and the Phoenix lander have generated data that astrobiologists are using to probe the martian environment for evidence of habitability and to further understand the history of water there. In 2011, NASA plans to launch its first dedicated astrobiology mission to Mars since Viking – the Mars Science Laboratory, a multi-billion-dollar lander/rover that will continue the search for past or present habitability on Mars.

On a smaller scale, the Astrobiology Small Payloads initiative is supporting instrument and concept development for small missions, including a proposed "ExoplanetSat" mission. Astrobiology's first Small Payloads project is a so-called nanosat mission known as O/OREOS (Organism/Organic Exposure to Orbital Stresses), which is scheduled to launch from Kodiak Island later this year. The NASA Ames Research Center's Small Spacecraft Division has developed the first triple-cube nanosatellite with two completely independent, interchangeable biological-and-chemical science payloads for the O/OREOS mission. The dual aim of this mission is to do science and demonstrate technology.

Astrobiology worldwide

Like many fields of research, astrobiology is inherently transnational. Australia, Canada, France, Germany, India, Russia, Spain, and the United Kingdom are among a growing number of nations that are funding astrobiology research. International collaborations in astrobiology are common, for data analysis, field research, flight experiments, and mission planning. Field sites for astrobiology research have ranged from Antarctica to Alaska, Australia, Canada, Chile, China, Mexico, Norway, and Hawai'i, as well as elsewhere in the continental United States.

In 2009, NASA and the European Space Agency (ESA) agreed to collaborate on a joint Mars exploration program. Astrobiology will be a primary focus of future missions to Mars. The ultimate goal for the joint NASA-ESA Mars program and the global astrobiology community is a Mars sample return mission.

NASA also collaborates with astrobiologists from other nations through international organizations such as the Committee on Space Research (COSPAR) of the International Council for Science. COSPAR's Scientific Commission F on Life Sciences as Related to Space has a Subcommission (F3) on Astrobiology, and COSPAR maintains a Panel on Planetary Protection that draws heavily on international astrobiology expertise to define measures to avoid planetary cross-contamination.

The science community organizes biennial astrobiology science conferences (called "AbSciCons") to report on latest research findings and plans for future studies. AbSciCon 2010 took place in April in League City, Texas, drawing more than 700 attendees.

Among key science questions addressed at this meeting were: Did life on Earth begin in an "RNA world," a "DNA world," or some other kind of world? What was early Earth like, and how and when did it become habitable? How hellish was the Hadean Earth? How do catastrophic events, such as asteroid or comet impacts, shape planetary environments and affect habitability?

In 2011, astrobiology will be a major topic at "ORIGINS 2011," next year's joint meeting of ISSOL: The International Astrobiology Society and the International Astronomical Union's Bioastronomy Commission.

Public perceptions and the future of astrobiology

If the first 50 years provide any hints, what we can expect to learn about life in the universe over the next 50 years is, to put it simply, the unexpected. Thirty years ago, for example, the scientific consensus was that Mars was, and likely always had been, cold and dry and lifeless. Today, the consensus is that Mars was, and perhaps still is, wet and habitable, and space-faring nations worldwide are working on plans for the further exploration of this planet. Seasonally fluctuating quantities of methane in the atmosphere of Mars, detected in recent years, are of great interest to astrobiologists as a possible indicator of subsurface microbial life. The source of the methane could be abiogenic as well, and research is under way to resolve this mystery.

On Earth, the study of extremophilic life, virtually unknown when NASA initiated its exobiology program and spurred on by NASA support, is now a thriving and growing field of study whose importance extends far beyond the field of astrobiology. In attempting to learn about the origin and evolution of life, astrobiologists studying microbial communities in extreme environments on Earth have discovered in recent years that the limits within which terrestrial life can exist are far broader and that the diversity of microbial life here is far greater than scientists used to think. These findings are contributing to the important field of genomics (the study of genes and their functions), aiding planning for experiments and missions to search for evidence of possible life on Mars and other planetary bodies, and generally improving understanding of the nature and diversity of life.

The subject of astrobiology is of great interest to a wide variety of audiences, and this interest will continue to grow as astrobiology investigations are launched on a rising number of space exploration missions. Communication, education, and public outreach are important to the scientific enterprise of astrobiology, and student training is especially important to its future, from undergraduate to post-doctoral levels.

In scientific culture today, astrobiology is a well established, credible and legitimate field of study (though not a discipline, at least not yet). Outside the scientific community, astrobiology today is virtually a household word, and even people who might say they do not know what astrobiology is may be engaged with the work that astrobiologists do.

Enduring and widespread public interest in the origin and evolution of life and the possibility of extraterrestrial life is both a blessing and a curse. This broad, deep, cross-cultural engagement with the subject adds strength to the scientific rationale for astrobiology research and provides a great opportunity to foster science education with people of all ages. A challenge to improving public understanding of astrobiology is that the scientific definition of astrobiology is not necessarily the same as the public conception of astrobiology.

One aspect of the study of life in the universe that scientists have not yet found a way to adequately explain to non-expert audiences is the vast knowledge void that remains to be filled between scientific understanding of the emergence of life and the emergence of intelligence in life. Non-experts have far less trouble than scientists do in condensing and simplifying the immense "spaces" of time and complexity that lead to prebiotic chemistry and then to life, to molecules and then to cells, and to microbial life and then to intelligent life. They do this not because they are ignorant but mainly because they are not scientists. They are not trained to think like scientists. And persuasive arguments have been put forth they do not *need* to be.

The terms "astrobiology" and "SETI" – the search for extraterrestrial intelligence – are both widely recognized inside and outside the scientific community. What these terms mean to people outside the community is something that members of the scientific community might do well to understand better than they appear to. In its 2009 solicitation for research proposals, "Research Opportunities in Space and Earth Sciences"), NASA's Astrobiology Program places the study of the evolution of advanced life within the realm of exobiology and evolutionary biology research, as follows: "Research associated with the study of the evolution of advanced life seeks to determine the biological and environmental factors leading to the development of multicellularity on Earth and the potential distribution of complex life in the Universe."

Continuing interest in the subject of astrobiology contributes to demand for popular depictions of life in the universe that are not always scientifically sound. Adding to the complexity of the "educational challenge" facing astrobiology is that, for experts and non-experts as well, a wide range of opinions exists on exactly what "life" is, and what "intelligence" is. The shelves of libraries and bookstores are full of books about the scientific search for extraterrestrial life – for experts, non-experts, children, college students, for every conceivable audience. There is also, of course, a vast body of film and television takes on the scientific search for, and fictional encounters with, extraterrestrial life. Many pop-culture takes on extraterrestrial life – more colloquially, aliens – appear to rest on the assumptions that extraterrestrial life is common and like us and that intelligence is a typical result of evolution. How might the scientific community improve public understanding of these subjects? How might clarity be provided?

Conclusions

To wrap up, consideration of astrobiology in the broader cultural environment points to some challenges for the scientific community. An increasing focus of planetary exploration missions on astrobiological questions likely will lead to an even greater public focus on astrobiology, worldwide. While it is true that astrobiology has not yet yielded any evidence, or otherwise validated any claims, of the existence of extraterrestrial life, it is also the case that astrobiology remains a favorite topic in the popular media as well as in the science press. Discover magazine, the Discovery Channel, and The Learning Channel, and a growing archive of movies, television shows, and video games have no qualms about ignoring the boundaries between astrobiology, SETI, and even UFOlogy.

Nonetheless, over the past 50 years, scientists have constructed a solid theoretical framework and conducted research and observations to support the idea of the possibility – and, for some scientists, the probability – of extraterrestrial life. Consequently, NASA and other space agencies around the world take seriously the idea of extraterrestrial life, to the point where dedicated, multi-billion-dollar astrobiology missions are in development.

The possible discovery of extraterrestrial life, insights into the evolution of early Earth and the origin of life, and constraints on the future of life will challenge us to reconsider our views of nature and our place in the universe. Whether life is rare or common in the universe is to be determined. With the fast pace of extrasolar planet discoveries and efforts to identify Earth-like and perhaps even habitable planets, we are closer to finding out. Growing evidence of liquid water on Mars and the discovery of fluctuating quantities of methane in its atmosphere make the search for evidence of life there more compelling. The new NASA-ESA collaborative Mars exploration program will speed this search.

As the volume and complexity of scientific knowledge about the origins, evolution, and distribution of life in the universe grow, and as questions about the future of life in the universe continue to proliferate, astrobiologists will do well to be mindful of public interest in their research and tend to the task of communicating clearly, meaningfully, and often about their work.

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