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ASTROBIOLOGY

G. A. Soffen

NASA HQ, Code S, Washington, DC, USA

ABSTRACT

If we believe life to be a cosmic imperative, the understanding of life processes becomes a universal aspect of cosmology. How does life fit into our understanding of the universe. As a compliment to NASA's 'Origins' Program we are developing a new venture to embark on one of the great scientific questions of our time, our origins, evolution and our destiny. NASA already deals with a number of related biological questions. We are introducing a new unifying approach to biology within the NASA... Astrobiology.

Astrobiology is the study of the chemistry, physics and adaptations that influence the origin, evolution and destiny of life. We intent to raise the conscious level relating relevant biological questions to the formation and development of the universe through space missions and research programs. By linking certain aspects of exobiology, ecology, gravitational biology, and adding efforts in molecular biology, evolutionary biology, and planetary biology and joining this to Astronomy and planetology, we seek a deeper understanding of where the living process fits in to our cosmological theories.

We do this through laboratory experiments, space observations, computer modeling, missions and discovery of what appear to be extreme conditions for us, but conditions in which life thrives. NASA has formed an international 'virtual' Astrobiology Institute as a nucleus to initiate this consolidating idea. NASA's technology will play a major role in this endeavor.

Introduction

For most of the twentieth century, *biology* has not been a major scientific issue. It was used for the education of pre-medical students, applications in agriculture, or the field studies of naturalists. The great discoveries of Darwin and Mendel were classroom topics, while chemistry and physics marched ahead, propelled by industrial needs, wars and economics.

Now, we are entering a great age of discovery in biology. Molecular biology and genetic engineering are established fields, and biotechnology dominates the health care industry. Astrobiology has been introduced to a world whose interest in the stars has been kindled by the incredible Hubble pictures of our universe, the return to Mars, and the human occupancy of space as the indicators of the next century...when we will venture from our home planet and establish a toehold elsewhere.

The birth of Astrobiology, as a part of the vision of scientists, is echoed in the great leap of enrollment in the life sciences by university students, both nationally and internationally. In the twenty first century, most scientists will be life scientists, and most industries will be dependent, in part, on some biological processes. The next explosion in computers will be the vast networking derived from the study of neural nets. Information science will be closely linked to biological processes. Spectaculars, like the cloning of large animals and the discovery of human embryonic stem cells are merely the beginning; we still have not discovered most living organisms or their capacity to influence our social order.

What is the definition of Astrobiology ?

Astrobiology is the study of life in the universe; and the chemistry, physics, and adaptations that influence its origins, evolution and destiny. It addresses the question:

Is life a cosmic imperative?

What are the roots ?

Exobiology is a term coined in 1960 to define a field of study that concerns itself with extraterrestrial biology. Complementing the search for alien life forms, NASA recognized the opportunity to investigate the origin of terrestrial life by conducting laboratory experiments, and modeling the chemistry, which could be used to reconstruct the events that led to biogenesis on the Earth. At the same time, we developed strategies to search for similar or different forms of biota in the solar system (and possibly beyond). As we have extended our exploration of the solar system, a program was built of internal and extramural scientific studies. These prescribed the measurements, observations, and experiments from space, as well as in the laboratory. Ideas developed of the possible chemical-physical events that preceded the biogenesis of terrestrial-like biota. Theories arose about some of the events that may have taken place on Earth, following the early emergence of the successful self replicating organisms, that eventually gave rise to the ancestors of contemporary biota.

The Exobiology Program recommended missions to the most promising Earth-like candidate planet, Mars, to search for terrestrial analogues of modern terrestrial microorganisms that might be present in the Martian soil. The US Viking Missions performed simple tests for known processes of metabolism, growth and photosynthesis. These results were ambiguous! On-board the Viking spacecraft was also a very sensitive instrument for determining the organic composition of the surface material. To our surprise, there were *no organic compounds detected* in the Martian surface material (sensitivity of one part in a billion). In as much as many terrestrial meteorites coming from the Asteroid Belt bear several percent of complex organic material, it was *surprising* not to find any organic material on the surface of Mars, which is considerably closer to the Belt than Earth. The explanation accepted today is based on the supposition that Mars has some superoxidizing substances mixed in with the iron oxide that make up the red pigment of the surface. These presumed superoxides of iron are probably formed from the action of the unshielded incoming solar UV radiation. The existence of highly oxidizing materials would quickly decompose any organic material forming *de novo,* or of meteoric origin. Since Mars has intense global dust storms annually, we presume that the entire surface is covered by this oxidizing material. This in no way precludes a Martian biogenic past, but it does suggest that there are no contemporary microbe-like organisms on most of the Martian surface. The conclusions are that the *easy search* for terrestrial analogues has not resulted in positive results, and further searches will have to be aimed at remnants of life or subsurface organisms (or at the polar regions).

For the past two decades, the 'Exobiology Program' has mostly focused on understanding the 'origins' of terrestrial life. These worldwide efforts to perform research in this challenging and scientifically important field have shed light on many possible pathways that lead from the chemical domain to the beginnings of biology on Earth.

In the Earth Sciences, NASA turned its attention to understanding the Earth as a planet. Using our capability to develop remote sensing to gather data bases, NASA developed a large Program called

Mission to Planet Earth. The concept is to observe the whole Earth for a long enough period of time to understand the changes that are taking place, both natural and human induced. If we can develop a baseline of knowledge about our environments on the Earth at this point in time, we may be able to assign future changes to those industrial or technological contributions over which we have some control. This may allow the people of the Earth to make decisions based on forecasting knowledge rather than dealing with the resulting problems when they reach the crisis stage. NASA's role is only to discover the way to obtain the data.

What is the NASA plan ?

Astrobiology is intended to include an even broader vision of the cosmic events than was addressed by the 'exobiologists' or the Earth scientists. We have a clearer understanding of the need to consider biogenesis as part of the entire cosmic processes, beginning with the formation of the elements, star formation, planetary formations, formation of organic molecules, initiation of replicating organisms, biological evolution, gravitational biology biogeochemical processes and human exploration. The limits to life and biological destiny are all interconnected and influenced by the changing physical universe.

Astrobiology is an emerging field that includes a broader group of disciplines than biology or biochemistry. NASA's ORIGINS Programs in Space Science addresses understanding the cosmic processes from the 'Big Bang' to contemporary solar and planetary events that make up our universe. In addition to the origins of life, we must also address the influences of physical-chemical factors on living organisms; factors such as gravity, solar and cosmic radiation, magnetic fields, and environmental factors that make up our ecology. Additionally, we must conduct observations of the Earth, where successful biota is influenced by the rapidly changing and dynamic bio-geo-chemical cycles, especially as modified by human technology. Finally, we are learning the scientific value of human explorers in space.

Astrobiology as an interdisciplinary area requires the cross-cutting talents of scientists, engineers, and technical experts who can pose answerable questions to give us a new perspective of our universe. It should not be confined by scientific orthodoxy, budgetary line items, agencies, or political boundaries. Astrobiology will develop a new vision. Modern thoughts concerning biological processes are best addressed by a broad spectrum of minds that are merged. Current advances in computation, modeling, instrumentation, and observation position scientists of the future for pioneering this new field.

NASA has initiated a new effort, the **NASA Astrobiology Institute** (NAI) (formerly NABI, renamed as NAI). On October 31,1997, NASA released a Cooperative Announcement Notice (CAN-97-OSS-1) which solicited proposals for membership in the NASA Astrobiology Institute. In the CAN, it was stated the intent to form a world class virtual Institute, open to any domestic or foreign organization, academic, governmental or private sector. The primary purpose of the NAI is to enable and promote interdisciplinary research in Astrobiology. We anticipate that the refinement of the definition of Astrobiology and the focusing of its scientific goals will be stimulated and formulated by the leaders in this new field, and that some of these leaders will be Investigators coming from some of the 'Member' organizations in the NAI. NASA will bring three things to the field. First, a technical capability to network the various consortia that would make up the 'Membership' organizations. Second, the opportunity to use its mission capability to help answer some of the most urgent questions. Last, NASA agreed to fund the selected NAI 'Members' for an extended period of time. The anticipated lifetime of the NAI is twenty years. Its initial budget is established at $9M and it is expected to grow each year depending on its success. In years to come, we envision increasing the membership, and increasing the budget accordingly. Ames Research Center (ARC) is planned as the lead Center.

Since NAI was planned as a cooperative venture, the proposers were asked in the CAN, for their institution's contribution to the effort. In addition to the scientific portion of the proposal, each institution was asked for a statement of their plans for education. This could take many forms such as graduate students, post doctoral fellows, addition of faculty, or undergraduate courses (or possibly dealing with young students or the general public).

The idea of 'virtual' collaboration is not new. Scientists already participate with one another using the internet tools. However, for the NAI, NASA will use its advanced technology to build a robust advanced state-of-the-art network between each of the 'Member' institutions. This will promote experimental collaboration and dialogue among hundreds of scientists and their graduate students around the world. Exchange of data, shared ideas, and a rapid flow of information is certain to be stimulated. An Investigator at one of the "Member' institutions is likely to be more informed of advances in Astrobiology than scientists as isolated individuals.

The selection of the 'Members' was based on a competitive process open to all. All interested NASA Centers (including ARC, which is the lead Center for Astrobiology) were required to propose and be judged along with all other institutions.

The scope of the NAI is envisioned to include all of NASA's Enterprises, Space and Earth Sciences, Life Science, and the Human Exploration and Development of Space. As a starting point NASA posed a number of general scientific questions to aid those interested.

The roles of the Director and of the 'Members' are spelled out, which includes the educational programs, use of discretionary funds, fostering collaboration and developing workshops.

The criteria for selection were based on scientific and technical merit in interdisciplinary research and stressed innovation and novel approaches. Long term commitment by the proposing institutions and dedication to training were important. Relevance to NASA programs in Astrobiology and outreach were items of consideration.

On Dec. 2,1997, 72 Letters of Intent arrived at NASA. On Jan. 30, 1998, 53 Proposals were received, 27 from US universities, 10 from research institutions, 7 from US Federal laboratories, 5 from foreign consortia, 2 from museums and 2 from private companies. Most proposals contained 70-80 technical pages.

The evaluation of these proposals as performed by an external Evaluation Panel of 31 scientists from all relevant disciplines who met in Washington, DC for one week. Subpanels were formed so that all proposals were scrutinized by numerous peer reviewers.
Long discussions were held in plenary sessions to explore all arguments.

The Evaluation Panel eventually ranked 11 of the proposals as those that should make up the initial membership of the Astrobiology Institute. NASA convened a Recommendation Committee who received the Report from the chairpersons of the Evaluation Panel. Those 11 institutions were selected by NASA's Selecting Official and all proposers were notified of the results.

Who was selected ?

The following 11 institutions are the initial 'Members' of the NASA Astrobiology Institute:
Harvard University: PI, Andrew Knoll: Planetary context of Biological Evolution. Understanding the coevolution of life and environments in Earth history. Integrated field and specimen-based investigations interpreted in light of insights drawn from comparative biology and research on contemporary geological and biogeochemical processes.

Univ. Cal. Los Angeles: PI, Bruce Runnegar: Prediction, detection and exploration of extrasolar planetary systems as possible abodes of life. Geobiology and biogeochemistry of the oldest record of life on Earth and Mars. Paleomicrobiology and the evolution of metabolic pathways in the Archean environment. Metabolic evolution, tree of life, and early fossil and geochemical records of life on the Earth. Detection of life in the Solar System using small spacecraft and exploration methods rehearsed on Earth.

Penn. State Univ.: PI, Hiroshi Ohmoto: Increase understanding of the connection between the changes in the environment and the change in the biota on Earth, especially during the early stages of evolution. Problem areas ; Environment of prebiotic Earth and origin of life, Roles of metals in origin and evolution of life, Timescale for the early evolution of life on Earth. Evolution of atmospheric O2, and terrestrial biosphere. Causes and consequences of diversification and extinction of metazoans.

Arizona State University: PI, John Cronin: Six areas of study. Organic synthesis in meteorites. Organic synthesis and the origin of life in hydrothermal vents. Origin and evolution of early photosynthetic systems. Processes of microbial fossilization, with applications to the Precambrian rock record. Evolution of complex systems in extreme environments. Exploration for habitable environments that could have sustained past or present life on Mars or Europa.

Univ of Colorado: PI, Bruce Jakosky: Origin and evolution of life on Earth, the environmental conditions necessary for the existence of life, the nature, habitability, and potential for life on the planets in our solar system, the formation of planets around other stars, the potential for life, and the philosophical/religious significance of the search for life
Specific topics are: formation of stars and planets, habitability of the planets, origin of life and the RNA world evolution of life on the Earth and energetics of possible life on other planets.

Carnegie Institute of Washington: PI, Sean Solomon: Hydrothermal systems: Physical, chemical and biological evolution and cosmic environments. Organic chemical synthesis in water-rock systems varying temperature , pressure, and chemical constituents likely to be in terrestrial and extraterrestrial settings. Study distribution of volatiles (esp. water) throughout the solar system and other planetary systems. Predictive models and theoretical understanding and link to biology of submarine and terrestrial hydrothermal systems.

Scripps Research Institute: PI, Reza Ghadiri & Christopher Switzer (UC Riverside): Self-Reproducing molecular systems: & Darwinian Chemistry. This combined work addresses both experimental and theoretical approaches to self-replication which is a hallmark of life. How replication is coded, the kinetics of replication from random sequence populations, and the bearing on how natural systems work ('prebiotic soup'). Compartmentation and organismal identity will be taken up in studies of self-reproducing vesicles. Some work will focus on "single-biopolymer" forms which have both information repository and catalytic properties. This work will critically test the hypothesis that a polyelectrolyte structure is a universal structural feature of all biopolymers capable of Darwinian evolution.

Marine Biological Laboratory: PI, Mitchell Sogin: Environmental Genomes and the evolution of complex systems in simple organisms. Access biodiversity and evolutionary comparison among organisms using genetic sequences to measure genetic differences among genes within a single organism, members of populations, species and kingdoms. This will provide insights into the interaction of single-cell organisms and simple invertebrates with changing environments. This interdisciplinary approach will develop an understanding of the distribution of microbial diversity in extreme as well as moderate environments. This will explore the molecular processes underlying the establishment of bacterial symbionts in eukaryotic cells which may be the driving force in the evolution of nuclear genomes.

Ames Research Center: PI, David Des Marais: The context for life; the origin and early evolution of life; and the future of life. Combine spectral and chemical studies of laboratory analogs with quantum chemical calculations and astronomical searches to search for circumstellar habitable zones and follow the delivery of water to planets and other volatiles, and how climatic processes such as cloud formation can maintain water in its liquid state. Study how living systems emerged and how the Earth and its biosphere influenced each other over time, and how biospheres can be recognized. Future of life addresses the effect of rapid environmental change on ecosystem properties and the potential for survival and biological evolution beyond the planet of origin.

NASA Johnson Space Center: PI, David Mckay: Study of biomarkers in astromaterials. Investigation of known biomarkers and nonbiological processes which may form features closely resembling true biomarkers. Comparison of rocks, soils and diverse microbes and the effects of mineralization, fossilization, heat and impact shock on biomarkers and related features. This is aimed at determining how to recognize other biospheres in the search for life beyond the Earth.

Jet Propulsion Laboratory: PI, Kenneth Nealson: Coevolution of planets and biospheres. Understand the environmental context conducive to the maintenance of life on Earth or other planets. Determine the existence and nature of habitable environments outside the Earth. Identify approaches to confirm the existence of life, extant or extinct. The study of Mars as an analog: and the development of biosignatures that can be used to detect and identify life.

This is a virtual institute that will be network-linked electronically in order to carry out interdisciplinary research. Both graduate students and post doctoral Fellows will be selected who will migrate throughout the Astrobiology Institute to stimulate ideas and benefit from collaborative effort. In a year or so the Astrobiology Institute will be soliciting additional new members to fill in research areas that are needed and not covered by the initial members.

How will foreign nations be involved ?

In the original announcement, NASA included guidelines for Non-U.S. Participation, welcoming proposals from outside the U.S.. It stated that all proposals received would undergo the same evaluation and selection process as those originating in the U.S.. NASA received five non-U.S. proposals. None of those were selected. The same criteria were applied to the non-U.S. proposals as the U.S. proposals.

Several of the selected proposals have non-U.S. members on their team.

The intention is to build the NAI into a world wide Institute. The initial membership was selected to develop a firm foundation with clearly defined objectives and goals. At the time of the next addition of members , NASA plans to advertise more widely, to attract a broader part of world-wide institutions that have the resources and strength to participate.

What is the plan for developing the next generation of Astrobiologists ?

NASA recognizes the need to plan for the training of those scientists that will be entering this new field of study. These involve students, graduate students and post doctoral Fellows. Each of the selected 'Members' of the NASA Astrobiology Institute proposed a plan of how they would deal with the training and educational component for their particular organization. Overall, the concept is to use the strong internet linkage to develop a cohesion among those coming into the field at the same time. We anticipate each year there would be 10-20 new graduate students and post-doctoral Fellows working on projects in Astrobiology. They will come with different experiences and different emphasis. This should stimulate interdisciplinary ideas and research approaches. In the course of 5-10 years, there should be a sizeable group of peer scientists of similar ages in the pipeline coming from all over the world, that are linked through a powerful electronic media.