Introduction

Searching for an alien haven in the heavens

The first few articles in this issue of PNAS constitute the beginning of a two-part Special Feature dedicated to the study of astrobiology. Astrobiology is not an autonomous or self-sustaining discipline. Rather, it is a hybrid subject emerging at the crossroads of astronomy, geology, paleontology, physics, and biology. What at first pass may seem like an amalgamation of disparate fields, upon further review, is a clear and increasingly defined discipline. The roots of astrobiology are found in the 10 distinct goals set by the National Aeronautics and Space Administration (NASA) Astrobiology Institute. These objectives can be summarized into three branches: How does life begin and develop? Does life exist elsewhere in the universe? What is life's future on Earth and beyond?

Some preliminary answers to these questions were addressed at the first large scientific conference dedicated entirely to astrobiology, held April 25–26, 2000 at the Ames Research Center at Moffett Field, CA. A few months later an international "Frontiers of Life" conference was held in France's Loire Valley. Sessions at those meetings ranged from "Water—the Sine Qua Non of Life," which covered the water reservoirs on Jupiter's moon Europa; "Environment," which covered snowball earth, life in extreme environments, the evolution of biochemisty, and interstellar quinones; "Life Detection Methods and Biosignatures"; and "Detection Methods for Extrasolar Planets." Many of these topics are expounded in this issue of PNAS, and it is clear that the two premier conferences marked the official beginning of a wave of discourse that undoubtedly has as many opinions as voices.

Early astrobiology had some high-profile skeptics like French biologist Jacques Monod who in 1971 categorically dismissed the field. He reasoned that the "unfeeling immensity of the Universe" left one to conclude that biological organization emerged alone and by chance in a phenomenal chemical fluke (1). In 1964 American paleontologist George Gaylord Simpson (2) summarized the search for extraterrestrial life—and more particularly intelligent life—more bluntly, "a gamble of the most adverse odds in history." Recent skeptics include Peter Douglas Ward and Donald Brownlee (3), who reject the possibility of finding complex bioorganic material on other planetary bodies by emphasizing the staggering statistical improbability.

However, there have also been Nobel Laureates, world-renowned scientists, and trusted scholars who advocate astrobiology and the likelihood of finding bioorganic molecules and extraterrestrial life. Carl Sagan is perhaps the best-known father of astrobiology, but credit is also due to Christian de Duve, who heralded the existence of extraterrestrial biology as a "cosmic imperative" (4). During his term, Daniel Goldin, the first director of the NASA Astrobiology Institute, secured funding, space and mission time for the fledgling field. At the summer of 1999 meeting of the American Astronomical Society, Goldin optimistically declared that in the next century "scientists will debate the structure of continents and oceans, weather patterns, climates, storms, and the nature of seasons on dozens of new worlds." And with oceans, weather patterns, and storms, some assume come environmental conditions ripe for biological chemistry to emerge. In 1953 Harold Urey and Stanley Miller from the University of Chicago created such an environment when they mimicked the proposed "early earth" atmospheric conditions. After passing electricity through gaseous methane, ammonia, water, and hydrogen they were left with a "soup" mixture of amino acids. Astrobiologists hope to find a planet, other than Earth, where similar conditions could occur. Such a Urey–Miller-like planet would indeed be a rare, but not statistically impossible, Goldilocks planet as it would have to be not too hot, not too cold, not too small, not too large, and, at least until our current detection technology improves, not too faraway.

With only a small fraction of the new century underway it is premature to either quell or support Goldin's enthusiasm and aspirations for astrobiology. However, recent advances like the discovery of subsurface water reservoirs on Europa and aquifers on Mars, the increasing roster of "habitable" planets, and enhanced life detection techniques all have fostered an air of confidence among astrobiologists.

In this Special Feature issue the perspective by Christopher Chyba and Cynthia Phillips (5) gives an overview of our current knowledge about the environmental conditions on Europa. Jeffrey Bada's perspective (6) discusses the instrumentation challenges faced when undertaking extraterrestrial exploration. The paper by Norman Pace (7) addresses the nontrivial question of what are we looking for when we seek extraterrestrial biochemistry.

The next Special Feature issue will contain perspectives by John Rummel, NASA's planetary protection officer; and Baruch Blumberg, director of NASA's astrobiology institute coauthored with Michael Meyer, a NASA astrobiology discipline scientist. Their papers will cover topics including planetary protection, NASA's astrobiology directives, and life in extreme environments.

The research articles in these Special Feature issues touch on, among other areas, the topics of biosignatures, extrasolar planets and their habitability, modeling of environmental conditions and atmospheres, and life in extreme environments. As with all past Special Features, the perspectives and research articles will be accessible without the need for a subscription at www.pnas.org. We offer them to you as part of the Academy's long-standing tradition to foster pioneering research and innovative academic discussions. Fueled by science's increasing interstellar technology, funded by a $20 million annual NASA budget, fostered by private research funds of astronomical proportions, and followed by the public's unending curiosity to know whether we are alone in the universe, astrobiology may well emerge as *the* scientific discipline of this millennium.

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1. Monod, J. (1971) *Chance and Necessity: An Essay on the Natural Philosophy of Modern Biology* (Vintage, New York).
2. Simpson, G. G. (1964) *This View of Life: The World of an Evolutionist* (Harcourt, Brace, and World, New York).
3. Ward, P. D. & Brownlee, D. (2000) *Rare Earth: Why Complex Life Is Uncommon in the Universe* (Springer, New York).
4. de Duve, C. (1995) *Vital Dust: Life as a Cosmic Imperative* (Basic Books, New York).
5. Chyba, C. & Phillips, C. (2001) *Proc. Natl. Acad. Sci. USA* **98,** 801–804.
6. Bada, J. (2001) *Proc. Natl. Acad. Sci. USA* **98,** 797–800.
7. Pace, N. (2001) *Proc. Natl. Acad. Sci. USA* **98,** 805–808.