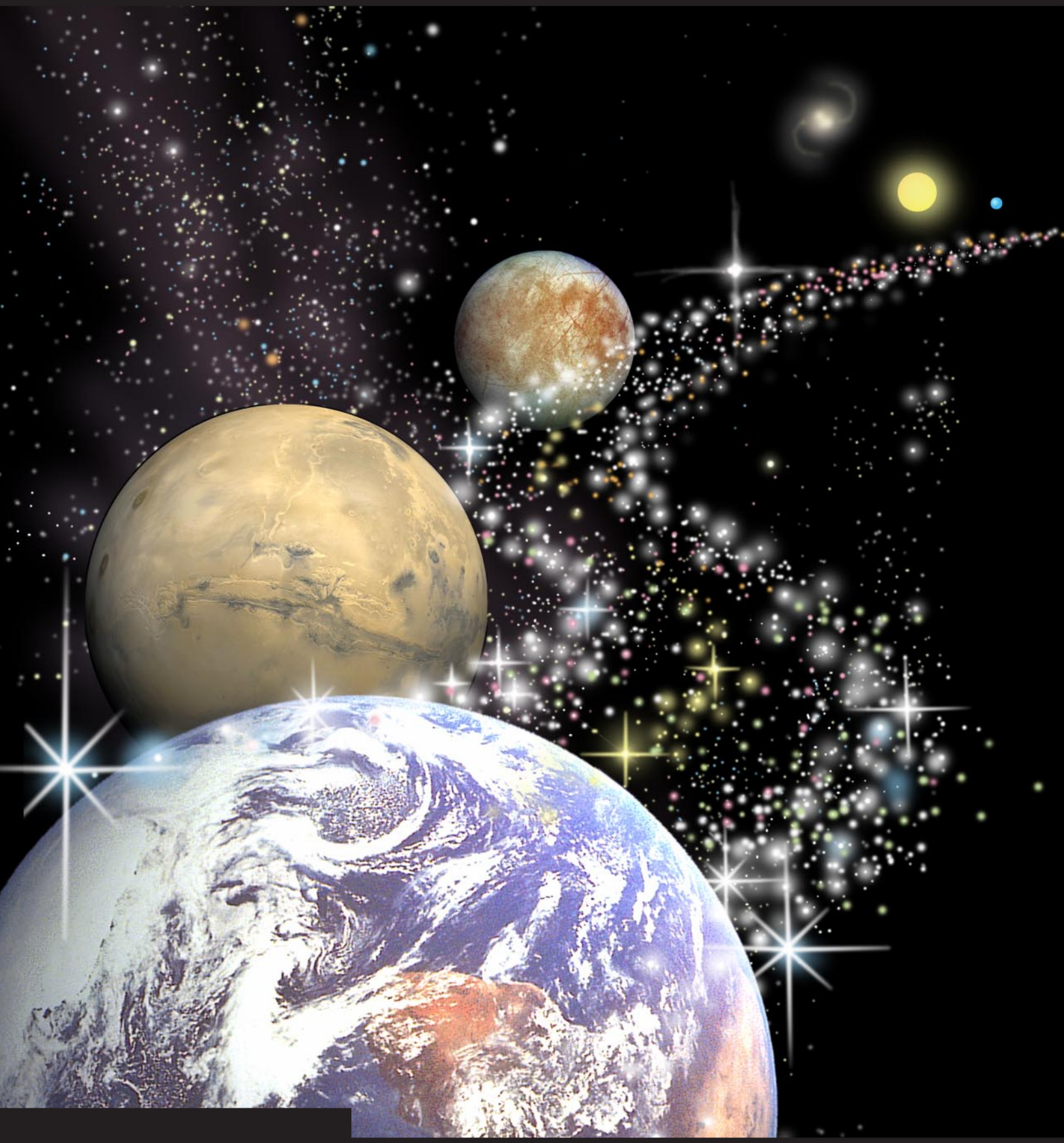

# APPENDIX

## ASTROBIOLOGY ROADMAP SUMMARY

Astrobiology is the study of life in the Universe. It provides a biological perspective to many areas of NASA research, linking such endeavors as the search for habitable planets, exploration missions to Mars and Europa, efforts to understand the origin of life, and planning for the future of life beyond Earth. The NASA Astrobiology Roadmap is the product of efforts by more than 150 scientists and technologists, spanning a broad range of disciplines. More than 100 of these individuals participated in a three-day Roadmapping Workshop held in July 1998 at NASA Ames Research Center.

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The Origins Strategic Plan draws heavily on the insights and recommendations of the Astrobiology Roadmap. Highlights of the Astrobiology Roadmap are presented here so that readers can see directly the linkages between the two.

### THREE FUNDAMENTAL QUESTIONS

Astrobiology addresses three basic questions that humanity has asked for generations. Astrobiology is born of the realization that we have the technology to begin to answer these fundamental questions:

*How does life begin and develop?*

*Does life exist elsewhere in the Universe?*

*What is life's future on Earth and beyond?*

The NASA Astrobiology Roadmap provides guidance for research and technology development across several NASA Enterprises: Space Science, Earth Science, and the Human Exploration and Development of Space. The Roadmap is formulated in terms of 10 science Goals and 17 more specific science Objectives. Realizing these Goals and Objectives will require specific focused programs, including flight missions as well as new instrumentation and facilities. Those pertinent to the Origins Theme have been described in detail earlier in this Roadmap. In addition, the NASA Roadmap emphasizes four principles that are integral to the operation of the Astrobiology Program. These principles are summarized after the Objectives.

## GOALS

In order to answer the fundamental questions, the Astrobiology Roadmap has identified 10 broad science Goals and 17 Objectives that follow from those Goals.

*How Does Life Begin and Develop?*

**Goal 1: Understand how life arose on Earth.**

**Goal 2: Determine the general principles governing the organization of matter into living systems.**

**Goal 3: Explore how life evolves on the molecular, organism, and ecosystem levels.**

**Goal 4: Determine how the terrestrial biosphere has co-evolved with Earth.**

*Does Life Exist Elsewhere in the Universe?*

**Goal 5: Establish limits for life in environments that provide analogs for conditions on other worlds.**

**Goal 6: Determine what makes a planet habitable and how common these worlds are in the Universe.**

**Goal 7:** **Determine how to recognize the signature of life on other worlds.**

**Goal 8:** **Determine whether there is (or once was) life elsewhere in our Solar System, particularly on Mars and Europa.**

*What is Life's Future on Earth and Beyond?*

**Goal 9:** **Determine how ecosystems respond to environmental change on time-scales relevant to human life on Earth.**

**Goal 10:** **Understand the response of terrestrial life to conditions in space or on other planets.**

## OBJECTIVES

*How Does Life Begin and Develop?*

**Objective 1:** **Determine whether the atmosphere of the early Earth, hydrothermal systems, or exogenous matter were significant sources of organic matter.**

**Objective 2:** **Develop and test plausible pathways by which ancient counterparts of membrane systems, proteins, and nucleic acids were synthesized from simpler precursors and assembled into protocells.**

**Objective 3:** **Replicate catalytic systems capable of evolution, and construct laboratory models of metabolism in primitive living systems.**

**Objective 4:** **Expand and interpret the genomic database of a select group of key microorganisms in order to reveal the history and dynamics of evolution.**

**Objective 5: Describe the sequences of causes and effects associated with the development of Earth's early biosphere and the global environment.**

**Objective 6: Define how ecophysiological processes structure microbial communities influence their adaptation and evolution, and affect their detection on other planets.**

*Does Life Exist Elsewhere in the Universe?*

**Objective 7: Identify the environmental limits for life by examining biological adaptations to extremes in environmental conditions.**

**Objective 8: Search for evidence of ancient climates, extinct life, and potential habitats for extant life on Mars.**

**Objective 9: Determine the presence of life's chemical precursors and potential habitats for life in the outer Solar System.**

**Objective 10: Understand the natural processes by which life can migrate from one world to another.**

**Objective 11: Determine (theoretically and empirically) the ultimate outcome of the planet-forming process around other stars, especially the habitable ones.**

**Objective 12: Define climatological and geological effects upon the limits of habitable zones around the Sun and other stars to help define the frequency of habitable planets in the Universe.**

**Objective 13: Define an array of astronomically detectable spectroscopic features that indicate habitable conditions and/or the presence of life on an extrasolar planet.**

**Objective 14: Determine the resilience of local and global ecosystems through their response to natural and human-induced disturbances.**

**Objective 15: Model the future habitability of Earth by examining the interactions between the biosphere and the chemistry and radiation balance of the atmosphere.**

**Objective 16: Understand the human-directed processes by which life can migrate from one world to another.**

**Objective 17: Refine planetary protection guidelines and develop protection technology for human and robotic missions.**

## OPERATING PRINCIPLES

The four Operating Principles that characterize the Astrobiology Program are:

**Principle 1: Astrobiology is multidisciplinary, and achieving our goals will require the cooperation of different scientific disciplines and programs.**

**Principle 2: Astrobiology encourages planetary stewardship, through an emphasis on protection against biological contamination and recognition of the ethical issues surrounding the export of terrestrial life beyond Earth.**

**Principle 3: Astrobiology recognizes a broad societal interest in our subject, especially in areas such as the search for extraterrestrial life and the potential to engineer new life forms adapted to live on other worlds.**

**Principle 4: In view of the intrinsic excitement and wide public interest in our subject, astrobiology includes a strong element of education and public outreach.**

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| 2MASS | Two-Micron All-Sky Survey |
| ACS | Advanced Camera for Surveys |
| ALMA | Atacama Large Millimeter Array |
| AMBRI | Australian Membrane and Biotechnology Institute |
| COBE | Cosmic Background Explorer |
| COS | Cosmic Origins Spectrograph |
| CSA | Canadian Space Agency |
| EPO | Education and Public Outreach |
| ESA | European Space Agency |
| FAIR | Filled-Aperture Infrared (Telescope) |
| FUSE | Far-Ultraviolet Spectroscopic Explorer |
| HST | Hubble Space Telescope |
| ICS | ion channel switch |
| IRSI | Infrared Space Interferometer |
| ISO | Infrared Space Observatory |
| KIA | Keck Interferometer Array |
| LF | Life Finder |
| LTSI | Large Telescope System Technology Initiative |
| MAP | Microwave Anisotropy Probe |
| NAI | National Astrobiology Institute |
| NASA | National Aeronautics and Space Administration |
| NGST | Next Generation Space Telescope |
| NICMOS | Near-Infrared Camera and Imaging Spectrograph |
| NRA | NASA Research Announcement |
| OSS | Office of Space Science |

| | |
|---|---|
| PAH | polycyclic aromatic hydrocarbon |
| PI | Planet Imager |
| PI | Principal Investigator |
| R&A | Research and Analysis |
| SDSS | Sloan Digital Sky Survey |
| SEU | Structure and Evolution of the Universe |
| SIM | Space Interferometry Mission |
| SIRTF | Space Infrared Telescope Facility |
| SOFIA | Stratospheric Observatory for Infrared Astronomy |
| ST-3 | Space Technology-3 |
| SUVO | Space Ultraviolet/Optical (Telescope) |
| TPF | Terrestrial Planet Finder |
| WFC3 | Wide-Field Camera 3 |
| WFC3-IR | Wide-Field Camera 3–Infrared |