IN SEARCH *of* OUR

First Footsteps, Copyright Julian Baum

C O S M I C R O O T S

"We shall not cease from exploration

And the end of all our exploring

Will be to arrive where we started

And to know the place for the first time.

Through the unknown, remembered gate

When the last of earth left to discover

Is that which was the beginning..."

T. S. ELIOT
FOUR QUARTETS

ORI

WE SEEK

TO OBSERVE THE BIRTH OF THE EARLIEST GALAXIES IN THE UNIVERSE, TO DETECT ALL PLANETARY SYSTEMS IN OUR SOLAR NEIGHBORHOOD, TO FIND THOSE PLANETS THAT ARE CAPABLE OF SUPPORTING LIFE, AND TO LEARN WHETHER LIFE EXISTS BEYOND OUR SOLAR SYSTEM. WE DO THIS TO UNDERSTAND AND EXPLAIN THE ORIGINS OF GALAXIES, STARS, PLANETARY SYSTEMS, AND ... LIFE.

WHERE DID WE COME FROM?
ARE WE ALONE?

Ever since humans became capable of thought and reason, we have pondered these questions. Our ancestors, huddled around their ancient campfires, must have wondered about such mysteries. The questions are abstract, and profound in their implications; yet seem so

GINS

natural that the youngest children gathered in modern classrooms ask them today.

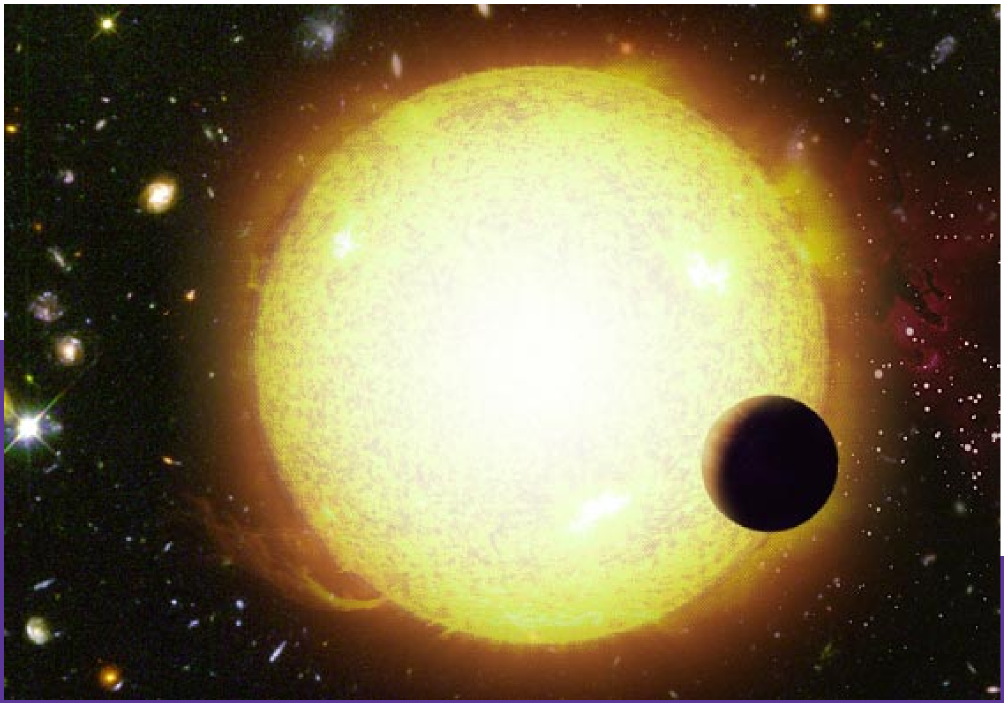
Our generation is privileged to live in an era in which advances in science and technology allow us to investigate these intriguing questions. While the questions can be simply stated, the scientific and technical foundations needed to answer them are challenging. In this document, we present a scientific Roadmap — with emphasis on the first decade of this century, followed by a vision for the far future — that will lead us to the answers that have eluded humanity for millennia.

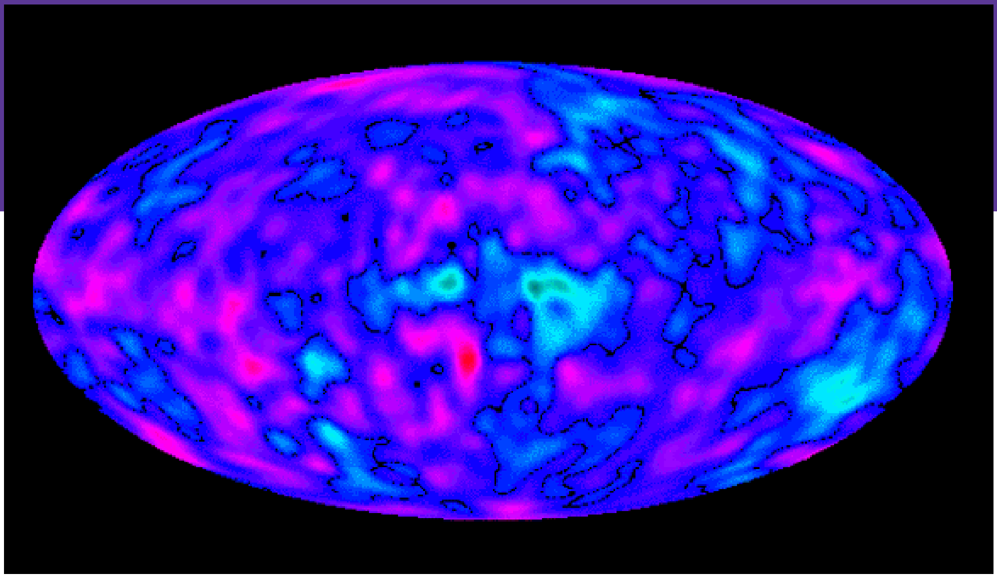
WHERE DID WE COME FROM?

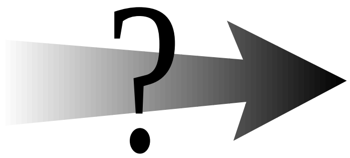
To answer this, we need to understand the astronomical, physical, planetological, and biological processes necessary to generate and sustain life on Earth.

ARE WE ALONE?

To answer this, we need to understand the building blocks of life and the conditions necessary for life to arise. We need to search our solar neighborhood to see if such conditions exist elsewhere. We need to search for signatures of life.





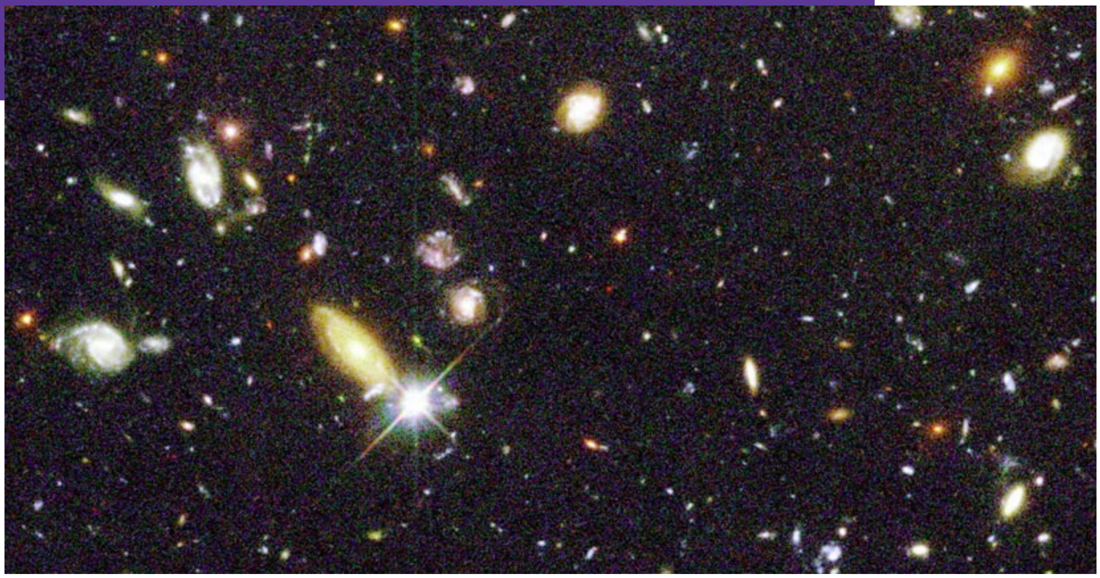


This Cosmic Background Explorer (COBE) image shows the very young Universe, which was remarkably formless, with subtle ripples hinting at grander structures to come. (Variations are enhanced through color coding.)

The Hubble Space Telescope image (above right) shows the Universe a few billion years older and already teeming with galaxies. A goal of Origins is to discover how the very first galaxies formed and transformed the featureless Universe.

Over the past several years, astronomical observations have begun to reveal the processes that ultimately gave rise to life several billion years after the Big Bang. Galaxies, the fundamental "building blocks" of the cosmos, have been observed as they were about a billion years or so after the origin of the Universe — but details of their formation have completely eluded all observations to date. Consequently, the most basic properties and processes of galactic birth are relatively unstudied. These studies await development of the Next Generation Space Telescope (NGST), which will have sufficient light-gathering power at mid- and near-infrared wavelengths to peer back to those critical periods of galactic formation.

Similarly, we know almost nothing about the appearance of the first stars, the more massive of which rapidly evolved through their lives and created within their nuclear furnaces the elements necessary for life. Such elements, subsequently expelled into interstellar space to seed the cosmos with the material required for complex chemistry, are most completely studied by observations at infrared and submillimeter wavelengths. Instruments planned for the



Stratospheric Observatory for Infrared Astronomy (SOFIA) are aimed at this type of observation.

New generations of stars and planets are believed to form out of this seed material — planets that now contain elements necessary for life. Stellar nurseries have been observed with increasing detail, although these observations have been mainly at visual wavelengths, which cannot penetrate the thick, dusty, circumstellar natal material. Flattened disks of dust and gas surrounding young stars that may harbor newly formed planets will be a major target for the next Origins mission to be launched: the Space Infrared Telescope Facility (SIRTF).

How common are planets outside of the Solar System? Are there any planets that resemble Earth? Although more than three dozen objects of substellar mass have been discovered orbiting stars in the solar neighborhood, observations to date show them all to be very massive, comparable in mass to gas giants like Saturn or Jupiter. These may or may not have formed in the same manner as the planets in our Solar System, and they might not be good examples of the basic characteristics of planet formation. None are likely candidates for biological activity. Both the Keck Interferometer Array (KIA) and the Space Interferometry Mission (SIM) will search for indirect evidence of much lower-mass planets than have been discovered to date, including planets almost as small as Earth.

A major goal of the Origins Theme is to search directly for warm, wet, Earth-like planets that may host biological activity. This is the goal of the Terrestrial Planet Finder (TPF). We also look ahead to larger constellations of telescopes, like the Life Finder (LF), that will detect spectroscopic signatures serving as *unambiguous markers for biology on distant planets, and we look even further to the time when we will see resolved images of other worlds with the Planet Imager (PI).*

THE SEARCH FOR LIFE

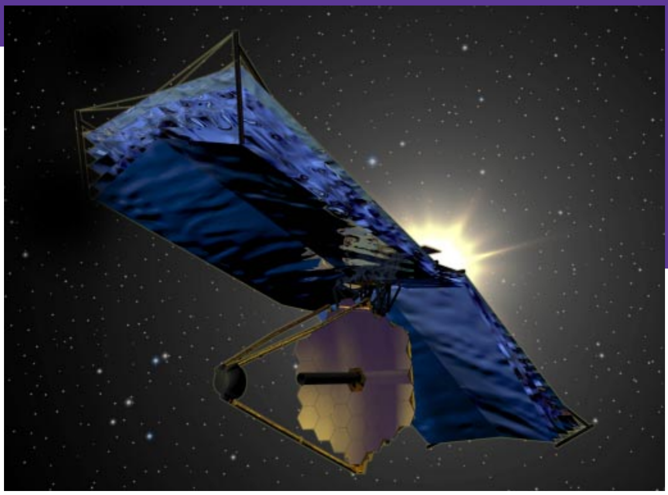
Although complex organic compounds are found throughout the interstellar medium, it remains an open question as to how this material survives the tumultuous events of stellar birth to enrich young planets with prebiotic material. Research work supported by the Origins Theme's Grants Program suggests that even very fragile organic material might survive atmospheric entry encapsulated within meteoric dust grains and cometary ices, which might subsequently rain down upon a young planet, seeding its surface with the material necessary for developing life. Discovering the origin of life and learning which aspects of the early terrestrial environment were essential to its emergence, survival, and evolution are among the goals of the National Aeronautics and Space Administration's (NASA's) Astrobiology Program, which is managed within the structure of the Origins Theme.

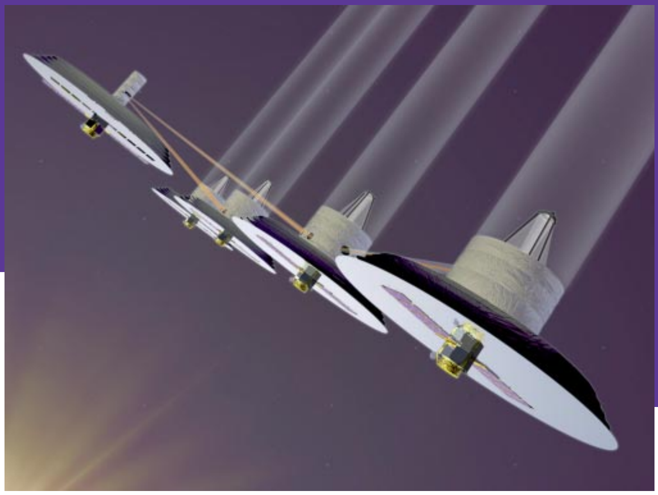
We are beginning to understand the processes that shaped the other planets in our Solar System. On Earth, we are learning about the diversity of life that exists in a wide variety of ecological niches. These advances only hint at the discoveries that await scientists working as part of the Origins Program, as they investigate the most fundamental and intriguing of astronomical phenomena, the emergence of life in the cosmos.

PROPOSED MISSIONS

As described in the following pages, the Origins Theme will investigate fundamental questions with a suite of missions over the next two decades that will profoundly alter the way humanity views its place in the Universe. Missions emphasized in this roadmap are those starting their implementation phase in the near-term (2003–2007) or mid-term (2008–2013) time frames. In the 2003–2007 window, this theme's highest priority for a new start is NGST, which will investigate the emergence of the very first galaxies in the Universe. After NGST, the next highest priority mission is TPF, which will identify and characterize Earth-like planets in orbit around nearby stars and search for signs of life on suitable candidate planets.

Two subsequent missions are viewed as natural technological and scientific follow-ons to these two high-priority missions. One is a very large (15- to 25-m), mid- to far-infrared Filled-Aperture Infrared (FAIR) telescope to investigate key processes in the formation of galaxies, stars, and planets. The other is a large (4- to 8-m) Space Ultraviolet/ Optical (SUVO) telescope.





Artist's concepts of NGST (above left) and TPF (above right).

TECHNOLOGY

A hallmark of the Origins architecture is that each major mission builds on the scientific and technological legacy of previous ones while providing new capabilities for future missions. Only in this way can the complex technological challenges of the Origins Theme be achieved at reasonable cost and acceptable risk. In pursuit of Origins' goals, we are looking at increasingly faint objects (such as early galaxies) or very small objects (such as planets around other stars). Only very large telescopes can attain sufficiently high sensitivity, and many of them would need to be arrayed together interferometrically to obtain high spatial resolution. Indeed, very large (15- to 25-m) telescope system technology is the common foundation of this theme for all future missions envisioned beyond TPF. For this reason, we propose the Large Telescope System Technology Initiative (LTSI) to lay the foundation for future Origins missions. This initiative will develop a technological "tool chest" to be used for Origins missions in the second decade and beyond in this century. This initiative will address all aspects of large telescope systems, including manufacturing, testing, packaging, and deploying lightweight gossamer-like primaries, active optics for phase-front correction, thermal management, and detectors.

Additionally, the Origins Theme will continue to lead in developing an increasing capability in spatial interferometry, particularly at IR and submillimeter wavelengths; precision formation flying; possible human servicing and human–robotic interaction; and computational systems for searching through the massive data sets generated by Origins missions.

EDUCATION AND PUBLIC OUTREACH

The Origins Theme's two defining questions — "Where did we come from?" and "Are we alone?" — are simple enough to discuss with children in elementary schools, yet are so profound as to challenge the world's scientific community and engage people in all walks of life. This provides us with a tremendous opportunity to structure a far-reaching Education and Public Outreach (E/PO) Program. We are committed to an E/PO Program that builds upon the theme's compelling defining questions and goals. It is aimed at exciting and involving the public and contributing to the education of the nation's children.

We intend to integrate E/PO throughout our flight missions and research programs by creating a cohesive portfolio of educational resources relevant to the classroom, yet drawn from the unique attributes of our research endeavors. We plan to blend outreach activities with the development of flight missions to build public understanding of the Origins Program. We also intend to engage the many scientists across the country who participate actively in the Origins Program in local, regional, and national E/PO activities. Our E/PO effort is a component of the Office of Space Science Educational Ecosystem, which is itself an element of NASA's overall education efforts. More details on this important facet of the program are provided later in this Roadmap.

ABOUT THE ROADMAP

This Roadmap is the product of deliberation and discussion by the Origins Subcommittee of NASA's Space Science Advisory Committee. The Subcommittee, working with representatives from many of the NASA field centers, as well as with substantial input from the astronomical community, examined both the scientific goals and objectives discussed in this Roadmap. The Roadmap sets out a plan for a roughly two-decade time span beginning in the year 2000, with particular emphasis on activities advocated for new starts in near-term (2003–2007) or mid-term (2008–2013) time frames.

The framework used to convey the Origins Roadmap is hierarchical. At the apex are the two Defining Questions: "Where did we come from?" and "Are we alone?" These questions allow us to communicate the thrust of this theme to the general public.

Below the questions are four scientific Goals involving endeavors that will not culminate in less than a few decades, and thus will remain constant for more than the five-year duration of one strategic plan (Roadmap). The Goals are the beacons that mark the path to the long-term scientific vision for the Origins Roadmap. Each of the four Goals has two scientific Objectives that are more specific and realizable on shorter time scales than the Goals. The scientific Objectives will be reexamined in each successive strategic plan, but may persist for more than one plan. Within each Objective are sets of one to three scientific Investigations. These Investigations (a total of 16) are critical because they define specific scientific studies and measurements that will allow us to achieve the Objectives and ultimately the Goals. The Missions and the Research and Analysis (R&A) activities advocated in this Roadmap are directly responsive to the identified Investigations and, therefore, are traceable to the Origins Theme's Goals and Objectives. Finally, the foundation of this hierarchical pyramid is an aggressive technology development program that makes possible the missions that are envisioned, which challenge the nation's technological capability. The schedule for missions presented here is one that recognizes that challenge and incorporates an unprecedented level of precursor technology testbeds, both on the ground and in space, to prepare for the major missions. This assures that mission schedules will be driven by technology readiness, not by preset launch dates.

The hierarchical structure of this Roadmap aimed at answering Origins' two defining questions starts with four long-term scientific Goals, each of which expands into two scientific Objectives and subsequently into a number of specific scientific Investigations. These Investigations can be translated into measurements and observations, some of which require one or more space missions. An extensive technology development program provides the foundation.