LIFE IN THE UNIVERSE

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

COMMITTEE ON SCIENCE

HOUSE OF REPRESENTATIVES

ONE HUNDRED SEVENTH CONGRESS

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LIFE IN THE UNIVERSE

THURSDAY, JULY 12, 2001

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE AND AERONAUTICS,
COMMITTEE ON SCIENCE,
Washington, DC.

The Subcommittee met, pursuant to call, at 10:10 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Dana Rohrabacher [Chairman of the Subcommittee] presiding.

Chairman ROHRABACHER. I hereby call this meeting of the Space and Aeronautics Subcommittee to order. And without objection, the Chair will be granted authority to recess the Committee. So ordered. I have also—would like to remind people that we have votes and we will be soon to go to those votes.

Now, I have always enjoyed Hollywood movies, like *"War of the Worlds."* I remember that as a young person. And "Independence Day," which was a great movie, as well. And "The Day the Earth Stood Still." I remember when the saucer landed right here in Washington, DC. That was a terrific movie as well. Unfortunately, the popularity of such movies changed our expectations regarding the search for extraterrestrial life in the universe. And I don't know if space aliens, like those that we saw in the movies, exist. But I do know that the science community is attempting to determine the existence of basic life on planets that are neighboring earth, as well as planets beyond our solar system. And with the help of scientific methods, we are just now beginning to answer a question that has existed since the dawn of humankind. And that is, are we alone?

At today's hearing, we will review real efforts concerning the search for life elsewhere in the universe. And I want to thank our distinguished member from Texas, Mr. Lamar Smith, for suggesting that this Subcommittee review this topic. And unlike Hollywood movies, Viking and Mars Pathfinder space probes allowed us to actually view the real Martian landscape and consider the possibility of water for supporting lifeforms on Mars and on other planets and other areas, and search for intelligent life across the universe.

Indeed, earth itself has provided us with a valuable insight as the—as to the possible nature of extraterrestrial life. Today we look to our panel of experts to explain how science will help us sort out fact from fiction. And I am sure there is going to be some questions, very provocative questions, concerning many areas. And we are just lucky that Bart has escaped his captors. Thank you very much. And I would now like to—first before we get to Bart for his opening statement, yield a few minutes to Lamar Smith, who, as I say, requested this hearing. And, Lamar, you may proceed.

[The prepared statement of Mr. Rohrabacher follows:]

PREPARED STATEMENT OF CHAIRMAN DANA ROHRABACHER

I have always enjoyed Hollywood movies like War of the Worlds, Independence Day, and The Day the Earth Stood Still. Unfortunately, the popularity of such movies changed our expectations regarding the search for extraterrestrial life in the universe.

I don't know if little green men exist. I do know that the science community is attempting to determine the existence of basic life on planets neighboring Earth, as well as planets beyond our solar system. With the help of scientific methods, we are just now beginning to answer a question that has existed since the dawn of humankind: are we alone? Today's hearing will review real efforts concerning the search for life elsewhere in the universe. I want to thank the distinguished member from Texas, Lamar Smith, for suggesting that the Subcommittee review this topic.

Unlike Hollywood movies, Viking and Mars Pathfinder space probes allowed us to actually view the real Martian landscape, consider the possibility of water for supporting basic life forms on Mars, and search for intelligent life across the universe. Indeed, Earth itself has provided us with valuable insight as to the possible nature of extraterrestrial life. Today we look to our panel of experts to explain how science will help us sort fact from fiction.

Mr. SMITH. Thank you, Mr. Chairman. And I thank the Ranking Member for letting me make my opening statement prior to his as well. I want to thank you, Mr. Chairman, not only for having a hearing on such an important subject, but also for assembling four such outstanding witnesses as we have here today.

The search of the heavens captures the imagination of the American people. Every summer it seems we have a blockbuster movie about space and other intelligent life. If we were to discover evidence of life in other parts of the universe, we will have made one of the most notable discoveries of our age, perhaps of all time.

Who hasn't looked into the sky and wondered about how life began and whether other beings inhabit other portions of our universe? T.S. Elliott wrote, "We shall not cease from exploration. And the end of all our exploring will be to arrive where we started and know the place for the first time." Author Timothy Ferris said that the fourth line of Elliott's poem is "cosmology's credo, for to find our place, we must know the place, cellar to ceiling, from the tap roots to the stars, the whole shebang."

Our desire to explore and discover life has led us to trek to the North Pole and circumnavigate the globe to conquer Mount Everest and plunge to the oceans' depths. We have even walked on a neighboring celestial body.

As we continue to explore and discover, we should also search the sky for signs of intelligent life. The discovery of other life in the universe would rate as one of the most astounding events in human history. We need to search the skies because not listening relinquishes any hope we have of solving the question: Does life exist elsewhere in the universe?

On other worlds in our solar system, from Mars to the moons of Jupiter, we have already begun the search for microbial life. And here on Earth, scientists continue to develop innovative technology and approaches to pioneer new radio techniques that could be used in the Square Kilometer Array, an international ground-based radio telescope project that will be 100 times more sensitive than the most sensitive existing radio telescopes.

We are compelled to search for other life in the universe to, in President Reagan's words, "Slip the surly bonds of earth and touch the face of God." Inherent in the human spirit is the desire to go farther, higher, and faster. The centuries-old quest for other worlds like our earth has been rejuvenated by the intense excitement and popular interest surrounding the discovery of giant Jupiter-size planets orbiting stars beyond our solar system. The challenge now is to find smaller planets in distant galaxies.

NASA is developing missions, such as the Terrestrial Planet Finder and the Next Generation Space Telescope, intended to detect earth-size planets. By the end of the decade, we will have combined the best imaging, formation flying, and other visionary technologies, giving us the power to move forward in answering the fundamental question: Are we alone? These projects and others remind us that our corner of creation is small and they allow us to ponder together the greatest questions one can ask.

Mr. Chairman, thank you again for the hearing, and thank you again for allowing me to make the opening statement.

Chairman ROHRABACHER. Well, we appreciate you requesting this hearing. I know that many of our scientists believe that the search for intelligence—intelligent life here in the Nation's capital is perplexing enough. So, Mr. Gordon, do you have an opening statement?

Mr. GORDON. Thank you, and good morning. I would like to welcome the witnesses to today's hearings. We have a distinguished group of scientists with us this morning, and I am sure that the topic of life in the universe will lead to a lively discussion. Whether there is life beyond our planet Earth is one of the fundamental scientific questions of humanity. In addition, the search for extraterrestrial life also has philosophic and religious dimensions. We don't have time in this hearing to explore all of these dimensions, but I hope that the witnesses will be able to help us better understand at least the scientific issues involved.

For example, I would like to know more about the scientific assumptions beyond your research strategies and why you believe these assumptions are valid. But at this point, I think I should yield back my time and move on with this hearing. Thank you.

Chairman ROHRABACHER. Well, thank you very much. Mr. Lampson, would you like to have a short opening statement?

Mr. LAMPSON. Just a short statement, Mr. Chairman. Thank you very much. I want to welcome the panelists for being here and thank them for being here today and thank you for calling the hearing. What we are going to learn or hear about today is really largely about why we are making our effort in space and what we might be able to learn. And it is interesting, a couple of things to note. One of them is that we, just in the last week or so, sent up a probe with MAP—and I cannot say the words that that acronym stands for—but is going to give us an opportunity to see and explore billions of years into the past and hopefully learn things that will make a difference in our own lives and about what we are about as human beings.

It is also interesting to note that in this morning's *Washington Post,* there is an article regarding water detected on distant comets and that that—you know, what these discoveries can possibly mean as we explore, again, what we are all about as human beings here on earth.

I am looking forward to what these gentlemen have to say. And I would have to agree with my colleague, it is going to be a lively discussion. Thanks.

Chairman ROHRABACHER. Thank you, Mr. Lampson. Mr. Lampson is a very active member of this Subcommittee, and we appreciate that very much. So without objection, the opening statements of other members will be put into the written record, so we can get right to the hearing and to the testimony. Hearing no objection, so ordered. I also ask unanimous consent to insert at the appropriate place in the record background memorandum prepared for the—by the majority staff for this hearing. Hearing no objection, so ordered.

[The information referred to follows:]

HEARING CHARTER

SUBCOMMITTEE ON SPACE AND AERONAUTICS COMMITTEE ON SCIENCE U.S. HOUSE OF REPRESENTATIVES

Life in the Universe

THURSDAY, JULY 12, 2001
10:00 A.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Witnesses:

Dr. Neil Tyson, Hayden Planetarium; *Dr. Ed Weiler,* NASA Space Science; *Dr. Jack Farmer,* Arizona State University, NASA Astrobiology Institute; *Dr. Chris Chyba,* Search for Extraterrestrial Intelligence (SETI) Institute

1. Purpose of Hearing

On Thursday, July 12, 2001 at 10:00 am, in Room 2318 Rayburn House Office Building, the Subcommittee on Space and Aeronautics will hold a hearing *Life in the Universe* on the National Aeronautics and Space Administration (NASA) space science and astrobiology programs as well as a leading private, non-profit endeavor, the SETI Institute's Phoenix Program. The hearing will provide Committee members with the opportunity to review ongoing efforts to search for life elsewhere in the universe.

2. Panel

Dr. Neil Tyson is Director of the Hayden Planetarium in New York City and a Visiting Research Scientist in astrophysics at Princeton University. He will testify on the qualitative differences between the search for extraterrestrial life and other scientific fields of inquiry and discuss the public's appreciation of this multi-disciplinary field.

Dr. Jack Farmer is the Director and Principal Investigator of the NASA-funded Astrobiology Program at Arizona State University. His interests include early biosphere evolution and the microbiology and biosedimentology of thermal springs and other extreme environments. His testimony will focus on the search for extraterrestrial life in our solar system on Mars and Europa, one of the moons of Jupiter.

Dr. Edward Weiler is NASA's Associate Administrator for Space Science. Dr. Weiler is responsible for leading NASA's $2.4 billion Space Science Enterprise. This enterprise aims to achieve a comprehensive understanding of the origins and evolution of the Solar System and the Universe, including the beginnings of life and the question of whether life exists beyond the Earth.

Dr. Chris Chyba holds the Carl Sagan Chair for the Study of Life in the Universe at the SETI Institute in Mountain View, CA and is an Associate Professor in the Department of Geological and Environmental Sciences at Stanford University. His testimony will focus on the search for extraterrestrial intelligence at the SETI Institute's Phoenix Program, a privately funded continuation of the government-funded High Resolution Microwave Survey.

3. Background

Are we alone in the universe?

There is a probability that life—both primitive forms like microorganisms and intelligent life—exists in the universe in places other than the Earth. Scientists are already discovering conditions elsewhere in the universe in which life may exist. Recent discoveries of extrasolar planets, the existence of water on other planets and moons and possible microbes in Mars meteorites have created new avenues for productive research. Future discoveries will be based on the development of new spacecraft, telescopes, and other resources that will search for indications of these life forms.

Is there extraterrestrial life in our solar system?

Astrobiology is the study of life on other planets using scientific experience from the observation of life's evolution on the Earth. The recent discovery of terrestrial life forms known as "extremophiles" demonstrates that life can evolve and thrive in extreme climates and environments, such as underground, undersea, and in caves. These discoveries have led researchers to revise their understanding of the minimal requirements (i.e., liquid water, existence of carbon, geological heating and radiation shielding) necessary to sustain life.

The discovery of these "extremophiles" led many scientists to speculate that similar life forms might exist where similar conditions exist elsewhere in the solar system. The study of how these extremophiles adapt to harsh environments on the Earth combined with the discovery of possible fossils of microorganisms in Mars meteorites in 1996 spurred a great deal of scientific interest in the possibility of life on Mars and Europa (one of Jupiter's moons) where liquid water may exist.

Mars

Several Martian meteorites have been found on Earth, and some of them appear to contain the fossilized remains of microorganisms. These meteorites offer a rare opportunity to study the planet without actually retrieving the rocks from Mars.

While the evidence is significant, it is not conclusive proof of past life on Mars because of the ambiguity of the fossil's shape and the possibility that the meteorite may have been contaminated here on Earth. Scientists continue to search for additional Martian meteorites in an effort to learn more about the possibility of life on Mars. However, analysis of these meteorites will probably not scientifically prove that life existed on Mars. Further exploration of Mars will be necessary to prove whether or not life once existed or if life currently survives there today.

Today's Mars Exploration Program builds upon the efforts of the Mariner and Viking Mars probes in the 1970s and the Mars Global Surveyor and Pathfinder missions in the 1990s. The primary emphasis of the current program is to regard the planet as a dynamic system and study the past and present Martian environment, climate, and geology. This research will assess the biological potential of certain areas of the planet to better target future robotic missions designed to collect soil samples.

NASA's Mars Exploration Program plans a series of surveillance and reconnaissance missions along with in situ ground rovers and sample return missions. Launches are planned every 26 months when both the Earth and Mars are in orbital alignment. Each of the missions will use data gathered from the preceding ones to select areas of high biological potential. Successful operation of this mission will require the development of new technologies, such as smaller and more lightweight optics and radar, autonomous robotic operations, radiation-hardening, and nuclear power generation. Scout missions may include balloons and gliders designed to improve range and optical resolution.

The surveillance and reconnaissance missions will be followed by robotic rovers and later by sample return missions. The National Research Council recently recommended that a quarantine facility be constructed in order to protect the Earth's environment from possible alien microorganisms and protect the Mars sample from contamination.

Moon and Europa

While Mars is the most likely place to find liquid water elsewhere in the solar system, scientists also believe that the south pole of the Moon and Europa, the fourth largest moon of Jupiter, have ice water and may also have water in liquid form. Researchers using Lunar Prospector data verified the earlier discovery by the 1994 Clementine Mission of ice water on the south pole of the Earth's moon that was probably deposited from a comet.

While the lunar ice is probably not in liquid form and life is not likely to have formed there, Europa may have liquid water under its vast surface of ice fields that could harbor life. NASA's Europa Orbiter mission is planned for later this decade for the express purpose of this search. The satellite will be equipped with a radar-sounding device that will be able to locate ice/liquid interfaces underneath Europa's icy surface, a guarantee of the presence of water. The satellite will also be equipped with other instruments to map the surface and determine a point at which to drop a submarine-like probe that will melt through the ice and explore the oceans beneath.

Can we find Earth-like planets in other star systems?

It has been postulated that if there are Earth-like planets in other star systems, then perhaps life has evolved on these other planets. Currently, over seventy extra-solar planets have been discovered. However, these planets are extremely large—ranging from the size of the planet Jupiter in our solar system to over 15 times larger than Jupiter's mass. Astronomers find these planets by focusing their telescopes on nearby stars and observing changes in gravity and light. In order to locate smaller, Earth-like planets, optical telescopes with greater resolution than the Hubble

Space Telescope and Hawaii's Keck Interferometer Observatory must be developed. The Next Generation Space Telescope, Space Interferometer Mission, and Terrestrial Planet Finder spacecraft, which are planned within the next ten to fifteen years, may be able to find and take the first picture of Earth-like planets in other star systems.

Next Generation Space Telescope and Space Interferometer Mission

The Next Generation Space Telescope (NGST) and Space Interferometer Mission (SIM) will provide space telescope observations after the Hubble Space Telescope's mission is completed later this decade. While the NGST and SIM's primary objectives will be to answer cosmological questions about the universe, it will also be able to take ultraviolet images of stars and planets that are up to 400 times dimmer than those observable today by UV telescopes on the ground at the same resolution of the Hubble Space Telescope. This capability will greatly enhance the search for extra-solar planets.

The Terrestrial Planet Finder

The Terrestrial Planet Finder (TPF) is a NASA space mission currently under review whose primary mission will be to locate planets with Earth-like characteristics. The mission is scheduled to begin in 2010 and will identify planets that have the right chemistry and conditions to support life. Using spectroscopic instruments, scientists will measure relative amounts of gases like carbon dioxide, water vapor, ozone and methane. The goal of the TPF mission will be to find extra-solar planets suitable for sustaining extraterrestrial life and to find extra-solar planets suitable for future human exploration and colonization.

What indications do we have of intelligent extraterrestrial life?

While astronomers may find the conditions necessary to support life while focusing space telescopes at Earth-like planets in a variety of optical and electromagnetic wavelength spectrum, researchers working in the SETI Institute's Phoenix Program are using radio telescopes to conduct a wide area search of the heavens for possible communications between extraterrestrial life forms. Just as humans use radio and television broadcasts to communicate with one another, many scientists believe that it would be possible to intercept the transmissions of intelligent extraterrestrial communications that have traveled many light-years distance. Just as astronomers observe light from stars that is many years old, the radio transmissions from intelligent extraterrestrial life for which SETI listens would be similarly old based on the distance between the extraterrestrial transmitter and the Earth.

The search for intelligent extraterrestrial life involves multiple disciplines of study, including astronomy, planetary sciences, chemistry, biology, and sociology. This endeavor is not simply a government effort, as the SETI Institute proved when it successfully transitioned from a NASA program to a private, non-profit venture that provides grants to researchers and enlists the aid of volunteer scientists worldwide. The SETI Institute works in conjunction with university and government astronomers worldwide to build radio observatories and gather and process radio signals that may one day intercept the communications from intelligent extraterrestrial life.

4. Issues and Questions

What can be learned about the prospects of life on other planets from the study of life in extreme environments on Earth?

What priority should the search for extraterrestrial life take over other forms of scientific inquiry?

How much does the U.S. government spend annually on the variety of programs associated with the search for extraterrestrial life? How much do international space programs and private sector programs spend on this search?

Chairman ROHRABACHER. Today we have a distinguished Panel to explain their unique perspectives on the ongoing efforts to search for extraterrestrial life. We have asked them, and I would ask them, to summarize, if you can—that is a big summarize—of 5 minutes apiece so that we might engage in a question-and-answer session and get to some dialogue.

Our first witness is Dr. Neil Tyson, Director of Hayden Planetarium in New York City and Visiting Research Scientist in Astrophysics at Princeton University. Dr. Tyson, we welcome you, and you may proceed.

STATEMENT OF DR. NEIL DEGRASSE TYSON, DIRECTOR, DEPARTMENT OF ASTROPHYSICS AND HAYDEN PLANETARIUM, AMERICAN MUSEUM OF NATURAL HISTORY, NEW YORK CITY

PUBLIC INTEREST IN THE SEARCH FOR LIFE IN THE UNIVERSE

Dr. TYSON. Thank you, Mr. Chairman. I have the honor of summarizing, offering an overview of the scientific and cultural implications of the search for life in the universe and I would be happy to do that in the next 5 minutes.

The—I want to first call to people's attention the fact that the search for life in the universe, in many ways, is sort of a fundamentally different exercise than the search for other scientific truths. Not because the way scientists conduct it is different. People are still in labs and people still work on computers and still send space probes. The difference is really cultural. It is how the public reacts to the fact that we are conducting this search, compared with how the public reacts to almost any other kind of scientific result. And I want to shed some light on that.

First, let me comment that as an Astrophysicist and Director of the Hayden Planetarium in New York City, you may know that we have recently completed the construction of a new center for earth and space, the Rose Center for Earth and Space, a major facility that in the past year-and-a-half has attracted on average 1,000 people per hour to see our exhibitry, our space show, and the like. And this kind of exposure to the universe, from my reading of attractions, is without precedent. And I think it is a testament to public interest in what is going on in the universe. It is a firsthand measure of that beyond just the anecdotes that you get at cocktail parties.

One other point there is that we get a disproportionate frequency of media encounters up at the Rose Center for Earth and Space, I think, primarily because we are just six blocks north of the major news gathering headquarters of ABC, NBC, and CBS. And so if our knowledge of the universe flinches, there is a reporter up there asking us what our view is, given how much of the public we intersect.

And I would like to comment that no matter the scientific result, no matter what it is, one of the questions that the interviewer will ask is: "Is there life in this place that you are looking for?" or "How do we fit into that picture?" And it doesn't matter. It could be a star that just exploded, and the environment is 50 million degrees at its core. They will say, "Could there be life there?" It just doesn't matter—all the questions lead to: Is there life in the universe? And that is an important statement, because it not only happens in the media, as we know, it happens in everyday life.

If it happens that on an airplane, the person I sit next to finds out that I do astrophysics, that is the end of my solitude for the rest of the flight and all the remaining time is devoted to questions that they have harbored about the universe, leading off with the question, is there life elsewhere, usually followed by questions on whether—what are black holes and any insight I can offer on the Big Bang.

Now, there aren't that many astrophysicists in the world. There is about 6,000, among all the people in the world, numbering 6 billion. If you would ratio those two numbers, you would get 1 in a million. So there are not many of us doing this work. Yet, the media attention given to the work we do is extraordinary.

And I would like to call people's attention just—I just happen to collect these. You know, cover stories from *Time* Magazine and *Newsweek*—this is just 2 weeks ago. "How will the universe end?" *Newsweek*—"Mission to Mars." This one, "How did the universe begin?" And this is a point of pride in our community that we can help bring the universe to the public in a way that reaches popular culture. Here is one of my favorites: "Is anybody out there?"—cover story of *Time*. Now, of course, there is another side to that, as hinted by Mr. Smith, and that is, of course, that Hollywood has run away with this concept and that also makes headlines.

This particular one from a few years ago from *Time* Magazine, "The Aliens Have Landed"—this one has talked about "Independence Day" and the aliens in that film. By the way, I remain surprised that we could send a computer virus to their spaceship and bring them down when computers today have a hard time talking to each other. It apparently had no problems speaking to another species from another planet.

But the truth of these films, I think, is not so important as the fact that it has got people talking. And, as was already mentioned, but let me reaffirm, this question of our place in the universe and the question of whether there is life elsewhere in the universe, is not just an American question. We are not the only ones around asking this question, and the latter 20th century and beginning of the 21st century is not the only time we have ever asked these questions. If you look back through time, across cultures, people have wondered these very same questions no matter how far back you go.

And, in fact, one could argue that it was one of the major tenets of religion where you ask the questions: What is my place in this universe? Where do I fit? Where do I belong? One might ask, is the public investment in this effort proportionate to the public interest? And I think the answer to that would have to be, no, given how prevalent and—given how prevalent the search for life is in the minds and hearts of the public. Where will that take us in the future, however?

We are lucky to be living at a time where in our backyard—in our backyard—we have compelling evidence for the existence of liquid water under the surface of Mars, under the frozen surface of Europa, Jupiter's moon. As we know, life as we know it requires liquid water, so the search for life is, in some ways, defined by the search for liquid water. This is in our own backyard, tantalizing.

We also know that the chemistry of life on earth, certainly the chemical ingredients, hydrogen, oxygen, carbon, nitrogen, are some of the most common ingredients in this universe. Life somewhere else might just be chemically similar to us, even if it doesn't look like us.

So the point I want to leave you with is that the public cares deeply about this. They have always cared deeply about it. For the first time, we actually have a chance to address the problem head on through scientific inquiry. And unlike Giordano Bruno, who upon asking the question in the year 1600, "are there planets out there with life just like earth?" and having met—having been burned at the stake for having asked that question, we live in more tolerant times than that, and I would like to believe that these questions would be taken head on by sources of funding that finally match public interest. We owe it to our species. We owe it to our soul of curiosity. Thank you, Mr. Chairman.

[The prepared statement of Dr. Tyson follows:]

PREPARED STATEMENT OF NEIL DEGRASSE TYSON

The Search for Life in the Universe

An overview of the scientific and cultural implications of finding life in the cosmos

The discovery of what is now more than seventy planets around stars other than the Sun continues to stimulate tremendous public and media interest. In this case, attention was driven not so much by the discovery of the extra-solar planets themselves, but by the prospect of them hosting intelligent iife.

Nearly every space movie to come from Hollywood includes some encounter between humans and alien life forms. Most recently we have the high-budget Mars-based films *Mission to Mars,* and *Red Planet.* The astrophysics appears to be the ladder to what people really care about: whether or not we are alone in the universe. I have empirical evidence to support this contention. If the person on next to me on a long airplane flight ever finds out that I am an astrophysicist, nine times out of ten they ask, with wide eyes, about life in the universe. And only later do they ask me about the big bang and black holes. I know of no other discipline that triggers such a consistent and reliable reaction in public sentiment. This phenomenon is not limited to Americans. The time-honored question: "What is our place in the universe" might just be genetically encoded in our species. All known cultures across all of time have attempted to answer that question. Today we ask the same question, but with fewer words: "Are we alone?"

Ordinarily, there is no riskier step that a scientist (or anyone) can take than to make sweeping generalizations from just one example. At the moment, life on Earth is the only known life in the universe, but there are compelling arguments to suggest we are not alone. Indeed, *most* astrophysicists accept a high probability of there being life elsewhere in the universe, if not on other planets or on moons within our own solar system. The numbers are, well, astronomical: If the count of planets in our solar system is not unusual, then there are more planets in the universe than the sum of all sounds and words ever uttered by every human who has ever lived. To declare that Earth must be the only planet in the universe with life would be inexcusably egocentric of us.

Many generations of thinkers, both religious and scientific, have been led astray by anthropocentric assumptions, while others were simply led astray by ignorance. In the absence of dogma and data, history tells us that it's prudent to be guided by the notion that we are not special, which is generally known as the Copernican principle, named for the Polish astronomer Nicholas Copernicus who, in the mid 1500s, put the Sun back in the middle of our solar system where it belongs. In spite of a third century B.C. account of a sun-centered universe proposed by the Greek philosopher Aristarchus, the Earth-centered universe was by far the most popular view for most of the last 2000 years. Codified by the teachings of Aristotle and Ptolemy, and by the preachings of the Roman Catholic Church, people generally accepted Earth as the center of all motion. It was self-evident: the universe not only looked that way, but God surely made it so. The sixteenth century Italian monk Giordano Bruno suggested publicly that the universe was filled with planets that harbor life. For these thoughts he was burned at the stake. Fortunately, today we live in somewhat more tolerant times.

While there is no guarantee that the Copernican principle will guide us correctly for all scientific discoveries to come, it has humbled our egos with the realization that not only is Earth not in the center of the solar system, but the solar system is not in the center of the Milky Way galaxy, and the Milky Way galaxy is not in the center of the universe. And in case you are one of those people who thinks that the edge may be a special place, then we are not at the edge of anything either.

A wise contemporary posture would be to assume that life on Earth is not immune to the Copernican principle. If so, then how can the appearance or the chemistry of life on Earth provide clues to what life might be like elsewhere in the universe?

I do not know whether biologists walk around every day awe struck by the diversity of life. I certainly do. On this single planet called Earth, there co-exist (among countless other life forms), algae, beetles, sponges, jellyfish, snakes, condors, and giant sequoias. Imagine these seven living organisms lined up next to each other in size-place. If you didn't know better, you would be hard-pressed to believe that they all came from the same universe, much less the same planet. Try describing a snake to somebody who has never seen one: "You gotta believe me. There is this animal on Earth that 1) can stalk its prey with infrared detectors, 2) swallows whole live animals up to five times bigger than its head, 3) has no arms or legs or any other appendage, yet 4) can slide along level ground at a speed of two feet per second!"

Given the diversity of life on Earth, one might expect a diversity of life exhibited among Hollywood aliens. But I am consistently amazed by the film industry's lack of creativity. With a few notable exceptions such as life forms in *The Blob* (1958) and in *2001: A Space Odyssey* (1968), Hollywood aliens look remarkably humanoid. No matter how ugly (or cute) they are, nearly all of them have two eyes, a nose, a mouth, two ears, a head, a neck, shoulders, arms, hands, fingers, a torso, two legs, two feet—and they can walk. From an anatomical view, these creatures are practically indistinguishable from humans, yet they are supposed to have come from another planet. If anything is certain, it is that life elsewhere in the universe, intelligent or otherwise, will look at least as exotic as some of Earth's own life forms.

The chemical composition of Earth-based life is primarily derived from a select few ingredients. The elements hydrogen, oxygen, and carbon account for over 95% of the atoms in the human body and in all known life. Of the three, the chemical structure of the carbon atom allows it to bond readily and strongly with itself and with many other elements in many different ways, which is how we came to become carbon-based life, and which is why the study of molecules that contain carbon is generally known as "organic" chemistry. The study of life elsewhere in the universe is known as exobiology, which is one of the few disciplines that attempts to function with the complete absence of first-hand data.

Is life chemically special? The Copernican principle suggests that it probably isn't. Aliens need not look like us to resemble us in more fundamental ways. Consider that the four most common elements in the universe are hydrogen, helium, carbon, and oxygen. Helium is inert. So the three most abundant, chemically active ingredients in the cosmos are also the top three ingredients in life on Earth. For this reason, you can bet that if life is found on another planet, it will be made of a similar mix of elements. Conversely, if life on Earth were composed primarily of, for example, molybdenum, bismuth, and plutonium, then we would have excellent reason to suspect that we were something special in the universe.

Appealing once again to the Copernican principle, we can assume that the size of an alien organism is not likely to be ridiculously large compared with life as we know it. There are cogent structural reasons why you would not expect to find a life the size of the Empire State Building strutting around a planet. But if we ignore these engineering limitations of biological matter we approach another, more fundamental limit. If we assume that an alien has control of its own appendages, or more generally, if we assume the organism functions coherently as a system, then its size would ultimately be constrained by its ability to send signals within itself at the speed of light—the fastest allowable speed in the universe. For an admittedly extreme example, if an organism were as big as the entire solar system (about, 10 light-hours across), and if it wanted to scratch its head, then this simple act would take no less than 10 hours to accomplish. Sub-slothlike behavior such as this would be evolutionarily self-limiting because the time since the beginning of the universe may be insufficient for the creature to have evolved from smaller forms of life over many generations.

How about intelligence? Since there is still debate on how to define it and measure it in people, I wonder what the question even means when applied to extraterrestrials. Hollywood has tried, but I give them mixed reviews. I know of some aliens that should have been embarrassed at their stupidity. During a four-hour car trip from Boston to New York City, while I was surfing the FM dial, I came upon a radio play in progress that, as best as I could determine, was about evil aliens that were terrorizing Earthlings. Apparently, they needed hydrogen atoms to survive so they kept swooping down to Earth to suck up its oceans and extract the hydrogen from all the H_2O molecules. Now those were some dumb aliens. They must not have been looking at other planets en route to Earth because Jupiter, for example, contains over two-hundred times the entire mass of Earth in pure hydrogen. I guess nobody ever told them that over ninety percent of all atoms in the universe are hydrogen.

And how about all those aliens that manage to traverse thousands of light years through interstellar space, yet bungle their arrival by crash-landing on Earth?

Then there were the aliens in the 1977 film *Close Encounters of the Third Kind,* who, in advance of their arrival, beamed to Earth a mysterious sequence of repeated digits that were eventually decoded to be the latitude and longitude of their upcoming landing site. But Earth longitude has a completely arbitrary starting point—the prime meridian—which passes through Greenwich, England by international agreement. And both longitude and latitude are measured in peculiar unnatural units we call degrees, 360 of which are in a circle. Armed with this much knowledge of human culture, it seems to me that the aliens could have just learned English and beamed the message, "We're going to land a little bit to the side of Devil's Tower National Monument in Wyoming. And since we're coming in a flying saucer we won't need the runway lights."

The award for dumbest creature of all time must go to the alien from the original 1983 film *Star Trek, The Motion Picture.* V-ger, as it called itself (pronounced vee-jer) was an ancient mechanical space probe that was on a mission to explore and discover and report back its findings. The probe was "rescued" from the depths of space by a civilization of mechanical aliens and reconfigured so that it could actually accomplish this mission for the entire universe. Eventually, the probe did acquire all knowledge and, in so doing, achieved consciousness. The Star Trek crew come upon this now-sprawling monstrous collection of cosmic information at a time when the alien was searching for its original creator and the meaning of life. The stenciled letters on the side of the original probe revealed the characters *V* and *ger.* Shortly thereafter, Captain Kirk discovers that the probe was *Voyager 6,* which had been launched by humans on Earth in the late twentieth century. Apparently, the *oya* that fits between the *V* and the *ger* had been badly tarnished and was unreadable. Okay. But I have always wondered how *V-ger* could have acquired all knowledge of the universe *and* achieve consciousness yet not know that its real name was *Voyager.*

Regardless of how Hollywood aliens are portrayed, or how good or bad the films are, we must not stand in denial of the public's interest in the subject. Let us assume, for the sake of argument, that humans are the only species in the history of life on Earth to evolve high-level intelligence. (I mean no disrespect to other big-brained mammals. While most of them cannot do astrophysics, my conclusions are not substantially altered if you wish to include them.) If life on Earth offers any measure of life elsewhere in the universe, then intelligence must be rare. By some estimates, there have been more than ten billion species in the history of life on Earth. It follows that among all extraterrestrial life forms we might expect no better than about one in ten billion to be as intelligent as we are, not to mention the odds against the intelligent life having an advanced technology and a desire to communicate through the vast distances of interstellar space.

On the chance that such a civilization exists, radio waves would be the communication band of choice because of their ability to traverse the galaxy unimpeded by interstellar gas and dust clouds. But humans on Earth have only understood the electromagnetic spectrum for less than a century. More depressingly put, for most of human history, had aliens tried to send radio signals to earthlings we would have been incapable of receiving them. For all we know, the aliens have already done this and unwittingly concluded that there was no intelligent life on Earth. They would now be looking elsewhere. A more humbling possibility would be if aliens had become aware of the technologically proficient species that now inhabits Earth, yet they had drawn the same conclusion.

Our life-on-Earth bias, intelligent or otherwise requires us to hold the existence of liquid water as a prerequisite to life elsewhere. A planet's orbit should not be too close to its host star, otherwise the temperature would be too high and the planet's water content would vaporize. The orbit should not be too far away either, or else the temperature would be too low and the planet's water content would freeze. In other words, conditions on the planet must allow the temperature to stay within the 180 degree (Fahrenheit) range of liquid water. As in the three-bowls-of-food scene in the fairy tale *Goldilocks and the Three Bears,* the temperature has to be just right. When I was interviewed about this subject recently on a syndicated radio talk show, the host commented, "Clearly, what you should be looking for is a planet made of porridge!"

While distance from the host planet is an important factor for the existence of life as we know it, other factors matter too, such as a planet's ability to trap stellar radiation. Venus is a textbook example of this "greenhouse" phenomenon. Visible sunlight that manages to pass through its thick atmosphere of carbon dioxide gets absorbed by Venus's surface and then re-radiated in the infrared part of the spectrum. The infrared, in turn, gets trapped by the atmosphere. The unpleasant consequence is an air temperature that hovers at about 900 degrees Fahrenheit, which is much hotter than we would expect knowing Venus's distance to the Sun. At this temperature, lead would swiftly become molten and a 16″ pepperoni pizza will cook in nine seconds.

The discovery of simple, unintelligent life forms elsewhere in the universe (or evidence that they once existed) would be far more likely and, for me, only slightly less exciting than the discovery of intelligent life. Two excellent nearby places to look are the dried riverbeds of Mars, were there may be fossil evidence of life from when waters once flowed, and the subsurface oceans that are theorized to exist under the frozen ice layers of Jupiter's moon Europa. Once again, the promise of liquid water defines our targets of search.

Other commonly invoked prerequisites for the evolution of life in the universe involve a planet in a stable, nearly circular orbit around a single star. With binary and multiple star systems, which comprise about half of all "stars" in the galaxy, planet orbits tend to be strongly elongated and chaotic, which induces extreme temperature swings that would undermine the evolution of stable life forms. We also require that there be sufficient time for evolution to run its course. High-mass stars are so short-lived (a few million years) that life on an Earth-like planet in orbit around them would never have a chance to evolve.

The set of conditions to support life as we know it are loosely quantified though what is known as the Drake equation, named for the American astronomer Frank Drake. The Drake equation is more accurately viewed as a fertile idea rather than as a rigorous statement of how the physical universe works. It separates the overall probability of finding life in the galaxy into a set of simpler probabilities that correspond to our preconceived notions of the cosmic conditions that are suitable for life. In the end, after you argue with your colleagues about the value of each probability term in the equation, you are left with an estimate for the total number of intelligent, technologically proficient civilizations in the galaxy. Depending on your bias-level, and your knowledge of biology, chemistry, celestial mechanics, and astrophysics, you may use it to estimate from at least one (we humans) up to millions of civilizations in the Milky Way.

If we consider the possibility that we may rank as primitive among the universe's technologically competent life forms—however rare they may be—then the best we can do is keep alert for signals sent by others because it is far more expensive to send rather than receive them. Presumably, an advanced civilization would have easy-access to an abundant source of energy such as its host star. These are the civilizations that would be more likely to send rather than receive. The search for extraterrestrial intelligence (affectionately known by its acronym "SETI") has taken many forms. The most advanced efforts today uses a cleverly designed electronic detector that monitors, in its latest version, billions of radio channels in search of a signal that might rise above the cosmic noise. The "SETI At Home" screen saver analyzes real data (downloaded from the Internet) for an intelligent signal that rises above the din of cosmic noise. This software has been downloaded by more than 3-million PCs users around the world, which actively taps an astonishing level computing power from your plugged-in PC that would otherwise be doing nothing while you went to the bathroom. Indeed, "SETI At Home" is, by far, the largest computational project in the history of the world. I note that these projects in particular received their start-up funds from The Planetary Society, a 100,000-member organization that, among other objectives, promotes the search for life in the universe. Public support for this enterprise is real and it is deep.

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The discovery of extraterrestrial intelligence, if and when it happens, will impart a change in human self-perception that may be impossible to anticipate. If we don't soon find life elsewhere, what will matter most is that we had not stopped looking. Our species demands that we keep looking. Deep in our soul of curiosity we are intellectual nomads—in search of other places, in search of other life forms because we derive almost as much fulfillment from the search as we do from the discovery.

Chairman ROHRABACHER. Well, thank you very much. You should see what questions you get when you fly coach and you are a Congressman. It is the intent of this chairman that we—that Dr. Farmer will give his presentation and we have 12½ minutes before we have to vote. We will then recess until—I understand they have—this is a—it is journal vote and we might have a vote right after that. So we will be coming right after the next vote, or the last vote. That is the intent of the Chair. So it would be about a 10 to 15-minute break.

Dr. Farmer is from Arizona State University. He is NASA's Representative at the Astrobiological Institute. And Dr. Farmer, you may proceed.

STATEMENT OF DR. JACK D. FARMER, REPRESENTATIVE, ARIZONA STATE UNIVERSITY, NASA ASTROBIOLOGY INSTITUTE

Dr. FARMER. First of all, I would like to thank the Committee for inviting me to share my enthusiasm for this question about the search for life beyond earth. I am going to do that today from the perspective of exploring our solar system. I wanted to begin by just sort of setting a context. Rapid advances in science continue to expand our knowledge of the geobiological and evolutionary history of our planet and of the life upon it.

ASTROBIOLOGY

And in recent years, the interactions between sciences along these lines have become consolidated enough really to create a new field of science called astrobiology, which has been defined as the study of the origin, evolution, distribution, and destiny of life in the cosmos. Astrobiology is—continues to grow through these kinds of interactions and is, I think, having a big impact on the way that we view how we could go about looking for life elsewhere in the solar system.

Now, some of the more interesting and important advances in science that I would like to note really have occurred in the field of biology. And these concern, you know, a better understanding, really, of what constitutes our biosphere here on the Earth with the advent of molecular biology and the ability to go out and actually compare the genetic information that is stored in the cells of all living organisms and look at relationships. We have discovered a very important fact and that is that we live on a microbial planet. Basically, the higher forms of life, ourselves included, really constitute almost an afterthought, it seems, in biosphere development.

And so on that basis, microbial processes and the field of microbiology is having a big impact on the way that we think about not only our own planet, but the potential really for life elsewhere. And perhaps later in the discussion, I can talk in more detail about some of those important advances that have occurred in molecular biology.

I think one thing that has also come from this sort of expanded awareness of biodiversities, in the microbial sense, is that microbes have found an amazing array of different ways of making a living in their environment. It is almost astounding the number of different ways that organisms have found to explore different sources of energy in the environment and to expand to fill virtually every environment imaginable. These environments that organisms occupy, the microbes occupy, are very extreme to human—to our particular view of things.

However, there really are no barriers. If you look at pH, the full pH scale, from the most acid conditions to the most alkaline, you find microbes living there, doing quite well. From the highest temperatures that basically organic molecules can stay together, you find organisms living, all the way down to the—to basically subfreezing temperatures and very highly saline brines. So, I guess, if there is another lesson that has come out of our studies of biology and molecular biology is that life really has expanded to fill just about any niche where liquid water is available as sort of a universal medium to carry out its activities and where there is a source of energy and nutrients.

Well, this has obvious, you know, implications for how we might go about exploring for life in our own backyard here in the solar system. The range of environments that are available now for us to look at and, you know, and try to answer this question have expanded dramatically. At the same time, through NASA's programs of solar system exploration, we have expanded our understanding of what environments actually exist out there.

And so these are very exciting times. The discovery of water on other planetary objects in our solar system has opened up a whole new way of viewing exploration. And in the case of Mars, the driving premise now is Follow the Water. And we hope that if we follow the water, we will be able to answer the question.

So I think that these kinds of developments will continue to unfold, and this field of astrobiology will continue to grow. And the impact, of course, on solar system exploration will continue to be very important. And again, I—you know, I get very similar questions flying here last night. I was wearing my T-shirt with an astrobiology logo on it, and of course, I spent my whole plane flight out here talking about this with various people.

So it is a subject that is—has great public support and great public interest. And all of us are just very fascinated by the question and want to continue to do our best to try to answer it. So I will leave my comments there.

[The prepared statement of Dr. Farmer follows:]

PREPARED STATEMENT OF JACK D. FARMER

Exploring for Life in the Solar System

Introduction

The past two decades have witnessed a number of important advances in scientific knowledge that have contributed to our basic understanding of the nature and evolution of terrestrial life. These developments have opened up new possibilities for the existence of living systems elsewhere in the Solar System (and beyond) and have helped lay the foundation stones for a new interdisciplinary science called 'astrobiology', defined as the study of the origin, evolution, distribution, and destiny of life in the Cosmos (NASA 1997). This new discipline is characterized by a broadly based, interdisciplinary approach that embraces traditional fields of exobiology, exopalaeontology, planetology, astronomy, biogeochemistry, microbial ecology, molecular biology, among others. The following sections highlight some of the important discoveries that have changed the way we think about the development and persistence of life on Earth, while shaping our opinions about the potential for life elsewhere in the Solar System.

Growth of Molecular Biology: Earth's Microbial Biosphere

Recent advances in molecular biology have radically altered our view of the biosphere and the contribution of microbial life to overall planetary biodiversity. In contrast to the outdated five kingdom view of the biosphere (Animals, Plants, Fungi, Protists and Monera), multicellular plants and animals being given prominence, genetic sequence comparisons have shown there are actually three major domains (Archaea, Bacteria and Eukarya), consisting of dozens of kingdoms, nearly all of which are microbial (Figure 4). It is important to keep in mind that although we have sampled a wide range of environments, only a small fraction (1–2%) of the total biodiversity on Earth has so far been sampled (Pace 1996). While periodic discoveries of new organisms have increased the number of branches in the universal tree, the basic three domain structure has remained stable. Perhaps one of the most fundamental things we have recognized from this work is the fact that we live on a microbial planet where microscopic life fully dominated the first 85% of biospheric history. The pathways followed during the evolution of the biosphere appear to have been shaped by periodic environmental changes driven by basic processes of biological and planetary evolution. The occurred quite late in the history of our planet. Their explosive appearance of complex, multicellular animals about 600 million years ago, appears to have been triggered by the slow buildup of molecular oxygen in the oceans and atmosphere to the threshold level (about 10% PAL) required for oxidative metabolism. This event, which ultimately paved the way for human intelligence, has been attributed to the invention of microbial photosynthesis.

Expanding the Environmental Limits for Life

In the past decade or so, our knowledge of the environmental limits of life on Earth has expanded dramatically, primarily through the development of new sampling techniques and their application over a broad range of environmental extremes. A brief summary of some of the known environmental limits to terrestrial life is given in Table 1 (see also Figs. 2–3). Microbial species are known to occupy almost the entire range of pH from 1.4 (extremely acid) to 13.5 (extremely alkaline). Similarly, life also thrives over extremes in temperature, with some species showing *growth* up to ~114°C (thermal springs at Vulcano, Italy and deep sea vents; Stetter, 1996) and other species surviving down to −15°C (brine films in Siberian permafrost; Gilichinsky, 1995). Life also occupies an equally broad range of salinity, ranging from fresh water up to sodium chloride saturation (~300 percent), where salt precipitates. One thing seems clear: life occupies virtually every imaginable habitat on Earth where liquid water, an energy source and basic nutrients co-exist.

In addition to environmental adaptation, some microbial species also show evidence of remarkably prolonged viability. In even the driest deserts on Earth, some species survive by living inside porous rocks where they find a safe haven from UV radiation, springing to life only occasionally, when water needed for growth becomes available. Even more interesting are bacteria that have been germinated from spores preserved in Dominican amber dated at >30 million years old. Microbes have also been isolated from Siberian permafrost where they have remained in deep freeze for >3 million years, and other salt-loving microbes have been cultured from rock salt dated at hundreds of millions of years old (Figure 6). Given this propensity for prolonged survival, could life still persist on planets like Mars where Earth-like conditions once prevailed?

Energy Requirements for Life

In addition to the need for liquid water, the distribution and productivity of life is also determined by the amount of energy available for sustaining metabolism and growth. Most important is photosynthesis, which directly powers >99% of the biosphere's productivity. This observation is easily understood when we realize that energy from the sun, per unit area of the Earth's surface, is several hundred times more abundant than the thermal and chemical energy coming from within the Earth. Not surprisingly, life thrives virtually anywhere on the Earth that sunlight and liquid water co-exist. However, the story does not end there. In 1979, oceanographer and explorationist Robert Ballard and biologist J. Frederick Grassle piloted the deep submersible, Gilliss, to sites more than a mile and a half deep on the sea floor, near the Galapagos Islands. The mission was to relocate and describe in detail, warm vents and their associated faunas from several previously discovered sites. At these locations, scientists got a first glimpse of living ecosystems based entirely on chemical energy, instead of sunlight (Figs. 1 and 15). Finding such complex ecosystems, with large, multi-celled animals, all ultimately sustained by the chemical energy provided by the hot vents, was quite unexpected. As our exploration of "inner space" continued, we eventually discovered examples of these complex vent communities in virtually every ocean basin, proving the remarkable ability of these organisms to colonize even the most widely dispersed "island" habitats. There are now hints of primitive, pigmented photosynthetic organisms living at similar vent sites, which are able to utilize the weak thermoluminescent radiation given off by the hot vents (Blankenship et al., 2000). This has opened up the intriguing possibility that like chemotrophy, photosynthesis may also have evolutionary roots in deep sea vent settings.

As our methods of exploration and observation have improved, life's environmental limits have continued to expand. And we have not yet reached the limits! More recently it was discovered that life also thrives in deep subsurface environments where interactions between water and rock yield available energy (e.g., Gold, 1992; Fredrickson and Onstott, 1996). Also, we now think that Lake Vostoc, a subglacial lake lying deep beneath the Antarctic ice cap, may harbor a microbial ecosystem.

While many subsurface organisms utilize the "filtered-down" organic compounds produced by photosynthetic surface life, some species are able to make their own organic molecules from the purely inorganic substrates that come from simple weathering reactions between groundwater and rock (Stevens and McKinley, 1996). Such subsurface organisms hold special importance with regard to potential habitats for life elsewhere in the Solar System. For example, we must now seriously consider the possibility of a subsurface biosphere on Mars or Europa, where a subsurface hydrosphere may exist.

Impact Frustration of Early Biosphere Development

An important legacy of the Apollo missions was the development of a detailed cratering history for the moon. This led to the view that during early accretion, prior to ~4.4 billion years ago, surface conditions on the Earth were unfavorable for the origin of life (Chang, 1994). Frequent giant impacts would have produced widespread oceans of molten rock at the Earth's surface. Easily vaporized compounds, like water and biologically-important elements like carbon, hydrogen, oxygen, nitrogen, sulfur and phosphorous (necessary for life) would have been lost to space through a combination of volatile escape and impact erosion.

Models for the early accretion of the Earth suggest that by about 4.0 billion years ago, the rate and size of impacts dropped off to a point where the water and organics delivered to the Earth by comets and other icy objects, would have been retained. During this time (4.4–4.2 billion years ago), a stable atmosphere and ocean could have developed, providing the first suitable environments for pre-biotic chemistry and life. However, models also suggest that as late as 3.8 billion years ago, the emerging biosphere may have experienced one or more giant impacts. These impactors would have been capable of vaporizing the oceans, while sterilizing surface environments (Sleep et al., 1989; Zahnle et al., 1988). Such events would have "frustrated" the development of an early biosphere. The most protected habitat during this early period would have been in the deep subsurface, where as we have seen previously, life could have easily survived under hydrothermal conditions up to ~114°C.

Late, Giant Impacts and Early Biosphere Evolution

Using the genetic information encoded in the cells of living organisms, molecular biologists have been able to assemble a kind of "family tree" by comparing all of the species so far sequenced (Figure 4). This tree is based on genetic information stored in the RNA of ribosomes, small structures in cells that synthesize proteins. Because protein synthesis is extremely important in living systems, ribosomes appear to have been very conservative during their evolution, having sustained comparatively few mutations. Even minor mistakes in protein synthesis usually spell disaster to an organism and most mutations would not survive. Conservatism in the ribosomal genome has allowed it to retain more information about the evolutionary events that occurred during the early history of the biosphere.

On the basis of ribosomal RNA sequence comparisons, the first universal tree of life was published by Carl Woese (Univ. of Illinois) in 1987. It became quite evident at that time that the deepest branches of the tree, those presumably lying closest to the common ancestor of life, all shared an interesting property: a preference for very high (hydrothermal) temperatures exceeding 80°C. For some scientists this implied that life probably got started at high temperatures, perhaps within deep sea vent environments, as discussed above. For others (myself included) it seemed more likely that what we were seeing was not the environment of life's origin, but rather environments that prevailed after the last giant impact. Figure 5, which is based on the work of Kevin Zahnle (NASA Ames) and colleagues, summarizes the effects of a 400 km-diameter impact. Perhaps the most astounding effect predicted by his model is the complete evaporation of the oceans and the creation of a steam atmosphere. The most deeply rooted forms may simply be the descendants of organisms that were able to survive a comparable devastating late impact by hiding out in subsurface hydrothermal environments. Unlike today, such environments would have probably been widespread globally, following such an impact.

While this scenario is quite consistent with independent geological evidence for the early Earth (the rocks tell us it was hotter, that large impacts were more frequent and that volcanic activity was more widespread), recent discoveries in molecular biology have cast doubt on the reliability of the observed patterns in universal tree. It now seems clear that even for the conservative ribosomal tree, branching patterns have been complicated by the process of lateral gene transfer. This process involves the exchange of genetic information between branches and across the three domains of the tree (Doolittle, 1998). At one extreme, some workers have suggested that the three domains have no evolutionary meaning and are simply groups of organisms that have exchanged genetic material more often during evolution. In that case, no phylogenetic relationships would be preserved. More optimistically, it could be that instead of a branching tree, ancestor-descendant relationships are rather represented by a complex web of genetic exchanges that have occurred between species periodically throughout evolutionary history. Rapid advances are taking place in this area of science, and it is unclear what the outcome will be. But I still find the general consistency between the environmental predictions based on the RNA tree and the geological record quite compelling, and think the tree may preserve important information about biological evolution.

Evidence from Paleontology

The other way to look at evolutionary history is by reading patterns preserved in the fossil record. During Darwin's time, there was limited awareness of the importance of microbial life in the evolutionary history of the biosphere. The oldest fossils known were shelled invertebrates that appeared at the base of the Cambrian Period (now dated at ~540 million years). The first stromatolites (biolaminated sediments produced by microbial communities) were described around 1850, at about the same time Darwin's *Origin of Species* was published. But the significance of these structures basically went unappreciated until the late 1800's and the interval of Earth history preceding the Cambrian (called the Precambrian) was regarded as being largely devoid of fossils and life. However, new discoveries around the turn of the century began to add the dimension of deep time to paleontology, eventually pushing back the fossil record of microbial life billions of years (Barghoorn, 1971). In 1993, J. William Schopf (UCLA) reported bacterial microfossils from stromatolite-bearing sequences in western Australia dated at nearly 3.5 billion years. (Those microfossils have now been shown to reside in hydrothermal veins; Van Kranendonk personal communication, 2001.) Then in 1996, Steven Mojzsis (University of Colorado) and colleagues described possible chemical signatures for life from rocks in Greenland dated at almost 3.9 billion years. These are the current record holders for oldest probable fossils on Earth.

These advances in Precambrian paleontology have pushed back the record of life on our planet to within half a billion years of the time we believe the first viable habitats existed on Earth. This suggests that once the conditions necessary for life's origin were in place, it arose very quickly. Exactly how quickly, we don't yet know, but certainly on a geologic time scale, it was much shorter than previously thought. This view significantly improves the possibility that life could have originated on another planet like Mars, where liquid surface water may have only been present at the surface for a few hundred million years early in the planet's history. However, there is an interesting caveat here. If there has always been a subsurface hydrosphere on Mars, the widespread success of the subterranean biosphere on Earth suggests Martian life could have originated in subsurface environments at any time during the planet's history and persisted there until the present time (see below). The same also holds true for icy satellites with subsurface oceans, like Europa!

Exploring for an Extant Martian Biosphere

We began our exploration for life elsewhere in the Solar System more than twenty years ago with the Viking mission. Fixed robotic landers were delivered to two sites on the Northern Plains of Mars where they conducted biology experiments to explore for life. These experiments were designed to search for living organisms within surface soils. By adding water and nutrients to soil samples, it was anticipated that any organisms present would begin to grow and give off waste products that could be detected with the instruments on board (Klein, 1998). After nearly two decades of analysis, the results of the Viking biology experiments have been widely attributed to inorganic processes. This is perhaps not surprising given that liquid water, regarded as essential for living systems, is unstable at the surface of Mars today because of the low atmospheric density (~7.5 millibars at the equivalent of sea level). While we know there is water on the surface of Mars today, it exists primarily in a frozen state, or as minute amounts of vapor in the atmosphere.

Certainly the general absence of liquid water in modern surface environments on Mars poses a formidable barrier to the development and survival of life there today. But other important factors could also play a role in limiting habitability. First, the rusty, iron-rich soils of Mars are colored red because they are highly oxidized. The fact that Viking found no evidence for organic compounds in Martian soils, even though they are constantly being delivered to the surface by interplanetary dust particles, suggests that the surface soils are chemically harsh environments that are destructive to organic molecules. In addition, the thin, CO_2-rich atmosphere lacks molecular oxygen and an attending ozone shield to protect the surface from ultraviolet radiation. Many microorganisms on Earth are known to survive in high radiation environments by living within rocks, or by producing pigments that act as sunscreens. But UV radiation reaching the Martian surface is several times that considered lethal to most terrestrial organisms. True, some terrestrial microbes are able to survive in the high radiation environment of a nuclear reactor core by possessing extremely rapid DNA repair mechanisms. By itself, the surface radiation environment on Mars is probably not enough to limit the potential for life there. But, in combination these factors comprise a formidable barrier for life and it remains problematic whether biological systems could have adapted to such conditions. So if the surface soils sampled by Viking are not a favorable environment for life, where should we look for living organisms?

The subsurface of Mars offers a compelling environment for extant Martian life because models support the potential for an extensive subsurface ground water system located at a depth of several kilometers below the surface (Clifford, 1993). This suggestion was recently bolstered by the discovery of fluid seeps at the surface (discussed below). To access the deep subsurface of Mars will require larger and more sophisticated robotic platforms than are currently available. Alternatively, deep drilling might be accomplished by human astronauts. Clearly we will not send humans to Mars before we can be reasonably confident of their safe return. To gain this confidence, there are still many "tall poles" we must meet. Recent studies indicate it will take a decade of well-funded research to be in a position to decide the feasibility of human missions to Mars and another decade beyond that before we can actually mount a human mission.

Recently, the Mars Global Surveyor mission detected sites on Mars where water appears to have seeped out of the subsurface, forming small, very young channels (Fig. 7; Malin and Edgett, 2000). Interestingly, these seeps are only found on poleward facing slopes at high latitudes, perhaps the least likely places we would expect to find liquid water. The existence of these seeps suggests a source of groundwater very near the surface. But shallow crustal temperatures at these sites should be far below the freezing point of water. One way out of this dilemma is to appeal to brines (salt lowers the freezing point of water), or to subsurface hydrothermal circulation that would bring warm water to the surface at these sites. If liquid water (even hot, salty water!) is eventually proven to be agent that formed these features, then the biological potential for Mars will have been dramatically enhanced.

Exploring for a Fossil Record of Martian Life

At the same time the Viking landers were carrying out their biology experiments at the surface, images were being obtained from orbit that revealed a Mars more Earth-like early in the planet's history. Geomorphic evidence suggested that water was once widespread over the surface. Other geological arguments suggested that liquid water disappeared from the surface ~3.0 billion years ago. The loss of surface water has since been attributed to the gradual sequestering of the CO_2-rich Martian atmosphere in the crust as weathering products. In the absence of a recycling process, such as plate tectonics, the atmosphere would literally be drawn down into the crust and combined as mineral products. If surface life developed on Mars during the early Earth-like period of the planet's history, it is quite likely to have left behind a fossil record. As on Earth, this record should be preserved in ancient water-formed sedimentary deposits. On Earth we have found biosignatures in sedimentary rocks going as far back as we have intact sequences available to sample. By finding places on the Martian surface where we know water was once abundant, we should be able to access potentially fossiliferous deposits during the robotic phase of exploration. And by studying processes that govern the preservation of fossil biosignatures in analog environments on Earth, we have been able to define "rules" for preservation that can help us select the best sites on Mars to explore with future missions (Farmer, 1999; Farmer and Des Marais, 1999). This concept is an important part of the rationale for the current robotic program.

An Exploration Strategy for Mars

Given the complexity and scale of the problem, we cannot expect to land just anywhere on Mars and find evidence of past or present life. In formulating a strategy to explore for past or present Martian life, the Astrobiology community has recommended a phased approach where global reconnaissance is interleaved with precursor surface missions, in order to target the best sites for detailed surface reconnaissance and sample return (NASA, 1995). The basic goal is to target sites where there is evidence of past or present water activity and the right kinds of geologic environments (i.e., those favorable for the capture and preservation of biosignatures). In exploring for extant life forms, there is an obvious interest in finding habitable zones of liquid water in the subsurface. In exploring for a record of ancient life, we are more interested in targeting water-formed sedimentary deposits laid down by ancient hydrothermal systems (Fig. 9) or paleolake basins (Figs. 8, 15). Key to this endeavor is understanding the mineralogy of the Martian surface. Recent discoveries by the Thermal Emission Spectrometer instrument, currently mapping at Mars, emphasizes the point. Coarse-grained ("specular") hematite deposits detected at Sinus Meridiani strongly suggest the activity water. This is a site was previously identified as a paleolake basin based on geomorphology. This kind of synergy between instruments is exactly what we need to effectively "follow the water". This site has been short-listed as a potential landing site for the 2003 mission.

Placing an emphasis on understanding the past and present aqueous environments on Mars, will position us to target well-equipped robotic rovers to the best sites for *in situ* surface science and sample return. Ultimately this approach may afford us the opportunity to conduct *in situ* life detection experiments far more sophisticated than those of Viking, at sites that are much more likely to harbor evidence of past of present life. And by the careful selection of samples for return to our Earth-based labs, we will be able to carry out the types of sophisticated analyses that may be required to address the question of Martian life.

Life in a Martian Meteorite?

In 1996, a team lead by David McKay at Johnson Space Center posed a very intriguing hypothesis regarding the possible biological origin of about a half dozen features observed in Martian meteorite, ALH 84001. This now infamous igneous rock contains tiny grains of iron-rich carbonate, an aqueous mineral that precipitated in subsurface fractures as fluids flowed through. NASA wisely decided to open up the debate, providing grant funding to many leading scientists in this country and around the world to test the proposed hypothesis. This provided a remarkable opportunity to: 1) engage the public in the process of scientific inquiry and 2) bring the best minds together to tackle the problem. After several years of work, the community has systematically addressed all of the original lines of evidence posed. To date only one has survived detailed scrutiny. The remaining line of evidence is in many ways, perhaps the most intriguing. This involves tiny grains of the mineral magnetite (as the name implies, a naturally magnetic mineral) which is common in basalt (a high temperature volcanic rock that makes up oceanic crust). However, some bacteria have also "learned" to make minute grains of geochemically pure, low temperature magnetite, which they organize into chains within their cells and use as a kind of directional compass. This enables the cells to move about in their environment, tracking favorable environmental conditions. Some (about 20%) of the magnetites found in the Allan Hills meteorite bear a strong resemblance to the biologically-formed magnetites formed by terrestrial bacteria. But is the population of magnetites in the meteorite a reliable indicator of life? The community is still busy testing this idea by characterizing a broad range of naturally-occurring and synthetic forms of magnetite. Hopefully they will have a definitive answer soon.

If the last line of evidence for life in ALH 84001 comes up negative, what will this imply about the possibility of life on Mars? Remember that the Allan Hills meteorite was delivered happen-stance to the Earth millions of years after a random impact knocked it off the Martian surface and sent it hurdling toward the Earth. Another happen-stance discovery in Antarctica during a 1984 expedition eventually delivered the meteorite to the hands of scientists. Clearly there was not a lot of site selection involved in this process. I believe that for an adequate test of the hypothesis of Martian life we will need to have samples from sites where we are certain that conditions are/were right for the capture and preservation of biosignatures. This will take careful, systematic work. That is what the current Mars Program is striving to provide.

Our experience with the Allan Hills meteorite has served a crucial role in helping the scientific community to learn how to reliably test for signs of life in ancient rocks. This has been a great warm-up for analyzing the types of samples we hope to return from Mars during the next decade. But studies of ALH 84001 have also provided another important perspective. The ancient age of this meteorite, dated at 4.56 billion years, indicates that the ancient, heavily cratered highlands of Mars are likely to harbor a rock record that extends back in time to the very earliest period of the planet's history. On Earth, rocks of comparable geologic age have long since been destroyed by tectonic cycling, weathering and erosion. The fact that Mars never developed a vigorous plate tectonic cycle means that ancient crustal sequences are unlikely to have been deeply buried and metamorphosed. The loss of liquid water from the Martian surface early in the planet's history and the limited water-mediated weathering and erosion since that time, has also conspired to preserve an extraordinary record of early planetary conditions, and perhaps of life itself! The path we are on with the present Mars program, which emphasizes systematic exploration from orbit, interleaved with landed missions, should produce the important clues we need for selecting the best sites for detailed surface studies and sample return.

Exploring for Life in the Outer Solar System

Measurements of the magnetic field of Europa (a satellite of Jupiter) obtained during the Galileo mission, have strengthened arguments for the existence of a salty ocean lying beneath an exterior shell of water ice. (Similar arguments have now also been made for Ganymede and Callisto.) This idea of a subsurface brine ocean is also supported by infrared spectroscopic signatures which suggest the presence of magnesium and/or sodium sulfates in the surface ices of Europa. It has been postulated that the postulated Europan ocean is maintained by heating of the moon's interior through tidal friction, a process that could melt rock and drive a crustal heat exchange system. Indeed, the complexly fractured and largely, uncratered surface of Europa suggests that a form of ice "tectonics" involving the periodic upflow of liquid water from beneath the Europan crust, has constantly renewed the surface (Fig. 11–12). As the plates of ice diverged, water welled up from below, freezing out to form long, narrow ridges. Over time, ice plates shifted, offsetting older ridge segments along faults. At a finer scale, blocks of fractured crust foundered, tilted and became frozen in the leads between diverging plates. In addition to the long ridges separating plates, smaller, mounded features also formed where ice "volcanoes" erupted water, or ice.

In assessing the potential for life on Europa, certainly the presence of liquid water is crucial, both from the standpoint of providing a medium for biochemical processes, but also as a source of the chemical energy necessary to sustain it. A recent model by Chyba and Hand (2001) suggested that while photosynthesis does not provide a plausible energy source for life, radiation processing of Europa's ice and water, in combination with the decay of radioactive potassium, could decompose water to hydrogen and oxygen, with the hydrogen escaping to space. The chemical disequilibrium created by this process could be exploited for energy by organisms.

Exploration Strategies for Europa

On Earth, refrigeration is known to be an effective means for the preservation of organisms in high latitude and recently glaciated terranes. Sagan (1971) first suggested that microorganisms from an earlier, clement period in Martian history might still exist there today in a perpetually frozen state, preserved in ground ice. Could the same hold true for Europa? It seems quite plausible that where water has welled up from below, it may have carried organisms, or their by-products, from an underlying ocean or interstitial brine, eventually freezing and cryopreserving these materials in ices at or near the surface.

What are the chances that life could survive once entombed and frozen in ice? Terrestrial microbes have been shown to retain viability down to sub-zero temperatures by exploiting thin films of brine on the surfaces of mineral particles in permafrost soils (Gilichinsky et al., 1993). As mentioned previously, terrestrial organisms appear to have survived in a frozen state within Siberian permafrost for millions of years. Some have questioned the long-term viability of microorganisms in ice due to the destructive effects of prolonged exposure to background radiation, in the absence of active DNA repair mechanisms. Similarly, in the radiation-rich environment of Europa, this could also be a problem for long-term survival of organisms.

But viability arguments aside, as a potential fossil repository, ice could provide an equally important environment for preserving a fossil record of life on Europa. In exploring for cryopreserved life in Europan ices, sites where water/ice has recently erupted at the surface have obvious priority.

The next Europa mission is planned for launch sometime after 2007. This mission is expected to carry high resolution spectrometers to map the surface and determine the mineralogical and organic composition of the ice. In addition, radar sounding will be used to probe the subsurface from orbit in search of zones of liquid water. This will allow a more thorough test of the hypothesis of a subsurface ocean and help identify the best sites for surface exploration by robotic landers that will search for biosignatures cryopreserved in ices. If we are able to prove the existence of a subsurface ocean, the next step could be to deploy small 'cryobots' that will melt their way through the ice, deploying mini-subs to explore for signs of life in the "inner space" of the Europan ocean (Fig. 13). At present such ideas are just fanciful speculation. We lack the basic technology needed for this kind of exploration. But such ideas do provide a compelling vision for the future that inspires us to want to penetrate the icy veil of this strange world.

Summary

Recent scientific advances have greatly expanded our knowledge of the nature and evolution of terrestrial life, while opening up new possibilities for the existence of extraterrestrial life. These developments have laid the foundation for a new interdisciplinary scientific discipline called astrobiology, which studies the origin, evolution, distribution and destiny of life in the Cosmos.

Some important developments that have influenced the way we think about the exploration for extraterrestrial life in the Solar System include the following:

- Advances in molecular biology and paleontology have revealed that most of Earth's biodiversity is microbial. Microbiological processes drive many important biogeochemical cycles and have helped shape the global planetary environment during its history.
- The path of evolution followed by the biosphere was largely opportunistic, being intimately tied to processes of planetary evolution. But biological processes have also played a role. For example, the complex multicellular animals on the evolutionary path to humans, arose very late in biosphere history in response to the build-up of photosynthetic oxygen.
- Life has been shown to occupy a stunning array of environmental extremes, seemingly limited only by the distribution of liquid water, nutrients and sources of energy. This has opened up important options for the astrobiological exploration of the Solar System where many such environments exist.
- Complex microbial ecosystems, including large multicellular animals, were discovered living in association with hydrothermal vents on the deep sea floor. These ecosystems are unique in being sustained by inorganically-derived forms of chemical energy. This has important implications concerning the potential of such sources of chemical energy to sustain life in similar environments elsewhere in the Solar System (e.g., Europa).
- Subsurface environments on Earth harbor a vast biosphere that includes many species that can synthesize organic molecules from the simple by-products of inorganic chemical weathering. This discovery has opened up important new directions for exploring for life elsewhere in the Solar System.
- The structure of the universal tree of life, based on ribosomal RNA, suggests that the common ancestor of life lived in hydrothermal environments and utilized chemical energy. This idea is consistent with geological evidence for the early Earth, as well as with late, giant impact scenarios where low temperature surface organisms are exterminated, leaving behind only high temperature, subsurface forms. However, the relationships implied by genetic sequence comparisons have probably been complicated by lateral gene exchanges between unrelated species later in evolution, thus making it difficult to discern actual the patterns of descent. Still, the consistency with geological evidence suggests that molecular sequence data is telling us something important.
- Discoveries in paleontology have pushed back the record of life to nearly 3.5 billion years for cellular fossils and to nearly 3.8 billion years for chemical signatures of life. This shortens the time available for life's origin to less than half a billion years, indicating that once habitable conditions existed on Earth, life arose very quickly. This improves the chances that life may have

become established in surface environments on Mars during the short, early interval when water was widespread at the surface.

- The most probable environment for an extant Martian biosphere is the deep subsurface where a global ground water system may still exist. Plausible metabolic strategies involve the synthesis of organic molecules from compounds liberated by inorganic rock-water interactions. Recent seep sites strengthen the case for such environments, thus bolstering the potential for life.
- Deep drilling from robotic platforms poses a major technological challenge for Mars exploration, but access to subsurface aquifers with rovers may be possible at localized seep sites where upwelling hydrothermal brines appear to have escaped from the subsurface. Access to such sites will require advances in precision landing and long-ranging rovers.
- Exploration for evidence of an ancient Martian biosphere requires locating sites of ancient aqueous sedimentation, as well as paleoenvironments favorable for the capture and preservation of fossil biosignatures. A knowledge of the mineralogy of the Martian surface is considered crucial for targeting sites landed missions to explore for past life.
- The current strategy for the astrobiological exploration of Mars involves a phased approach where orbital reconnaissance will be interleaved with landed missions to narrow the search to a few high priority sites where we will carry out *in situ* surface exploration and sample return. This phased approach is designed to focus exploration efforts on the best sites for testing the life hypothesis.
- The hypothesis of fossil biosignatures preserved in Martian meteorite ALH 84001 has served as an effective catalyst in preparing the scientific community for Mars sample return by focusing the scientific community on the development of improved methods for assessing biogenicity in ancient terrestrial and extraterrestrial materials. Recent efforts have been focused on evaluating the origin of magnetite, a potential mineralogical biosignature found in the meteorite.
- Compelling evidence exists for a salty ocean beneath the icy crust of Europa. Plausible energy sources for life have been identified based on the disassociation of water by radiation processing at the surface and the decay of radioactive potassium in the subsurface.
- Future missions to Europa will test for a subsurface ocean from orbit as a basis for targeting sites of recent upwelling from the subsurface. Surface landers targeted to these sites will be able to explore for cryopreserved organic materials in surface ices and penetrate the subsurface environments where life may exist.

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Accompanying Illustrations:

- Table 1: Extremes of Life
- Figure 1: Deep sea vent community
- Figure 2: Yellowstone hot spring
- Figure 3: Mono Lake, CA
- Figure 4: rRNA Tree
- Figure 5: Zahnle impact scenario
- Figure 6: Halobacteria in salt crystals
- Figure 7: Martian seep sites
- Figure 8: Gusev crater paleolake basin
- Figure 9: Hydrothermal sites on Mars
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- Figure 11: Europa's crust
- Figure 12: Models for Europa's interior
- Figure 13: Hydrobot at Europa
- Figure 14: Aquifex
- Figure 15: Martian Lake beds

Table 1: Extremes of Life

Factor	Maximum	Minimum
Temp (degC)	113†	-15
pH	13	1.5†
Salinity (% NaCl)	30†	0
Water Activity (A w)	1.0	□0.6†

† Madigan et al. 1997

* Gilichinsky 1994

Figure 1: Deep sea vent community


Figure 2: Yellowstone hot spring

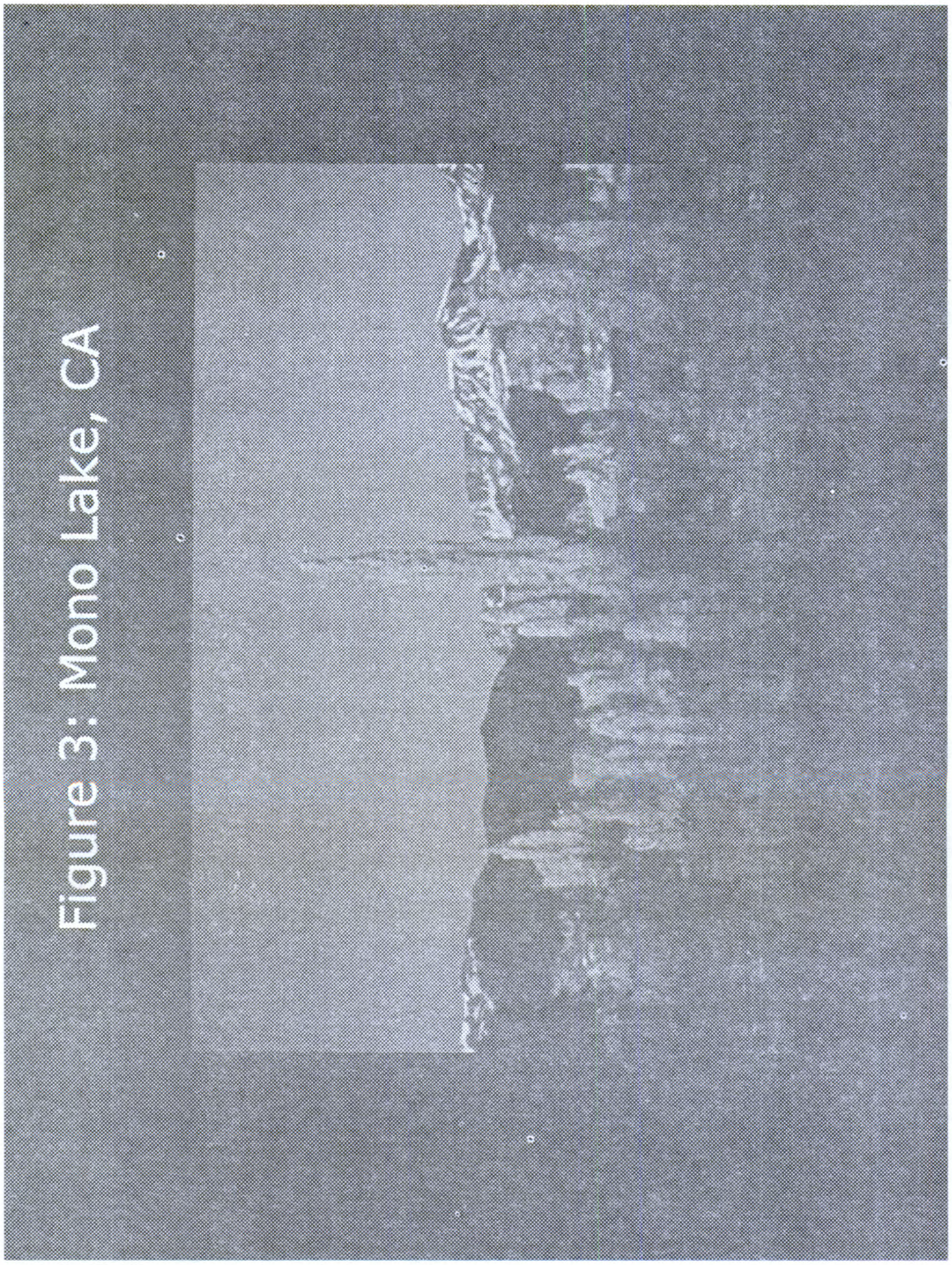


Figure 3: Mono Lake, CA

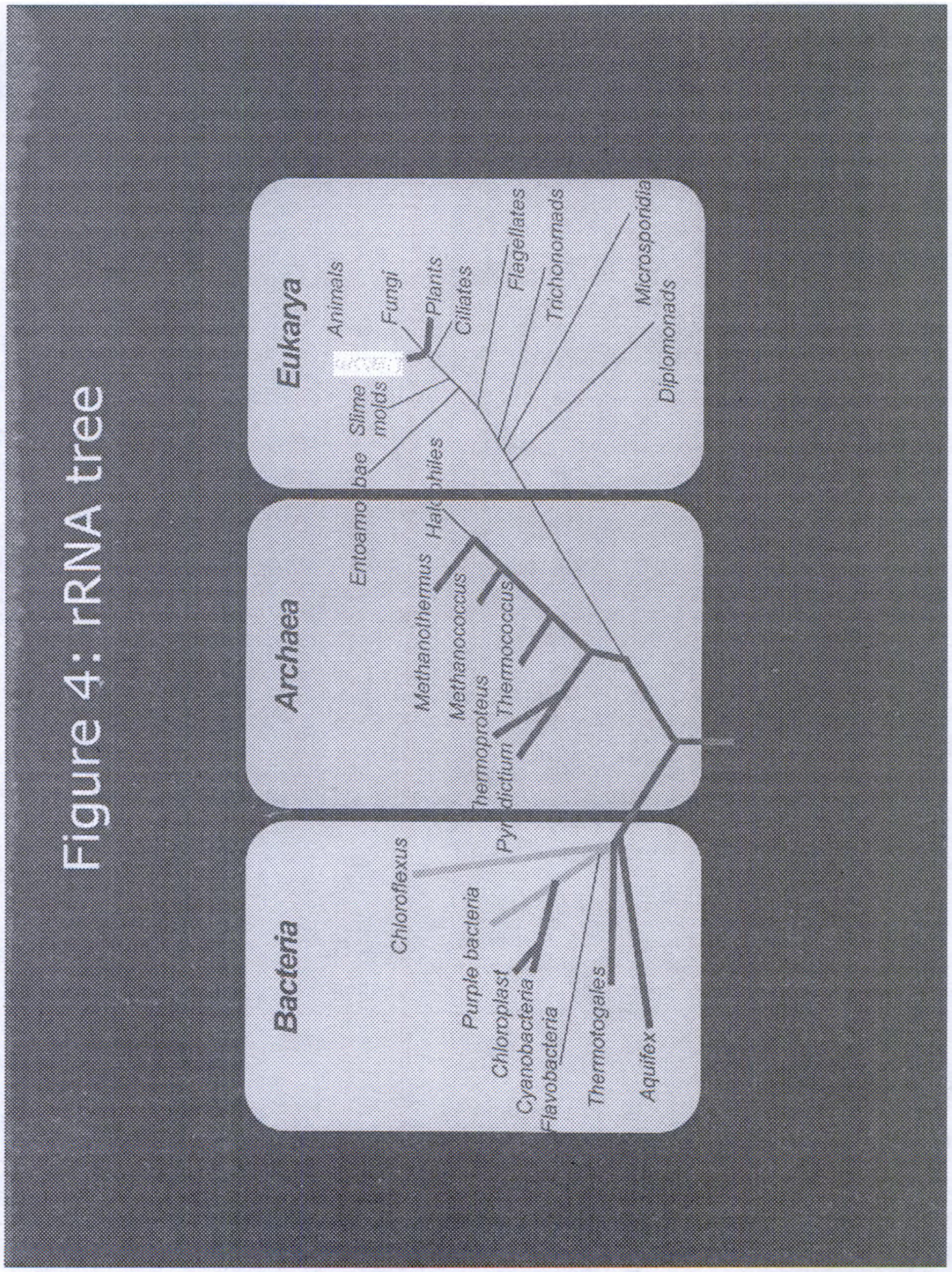


Figure 4: rRNA tree
Bacteria
Archaea
Eukarya
Chloroflexus
Purple bacteria
Chloroplast
Cyanobacteria
Flavobacteria
Thermotogales
Aquifex
Thermococcus
Methanococcus
Methanothermus
Entoamoebae
Slime molds
Animals
Fungi
Plants
Ciliates
Flagellates
Trichomonads
Microsporidia
Diplomonads

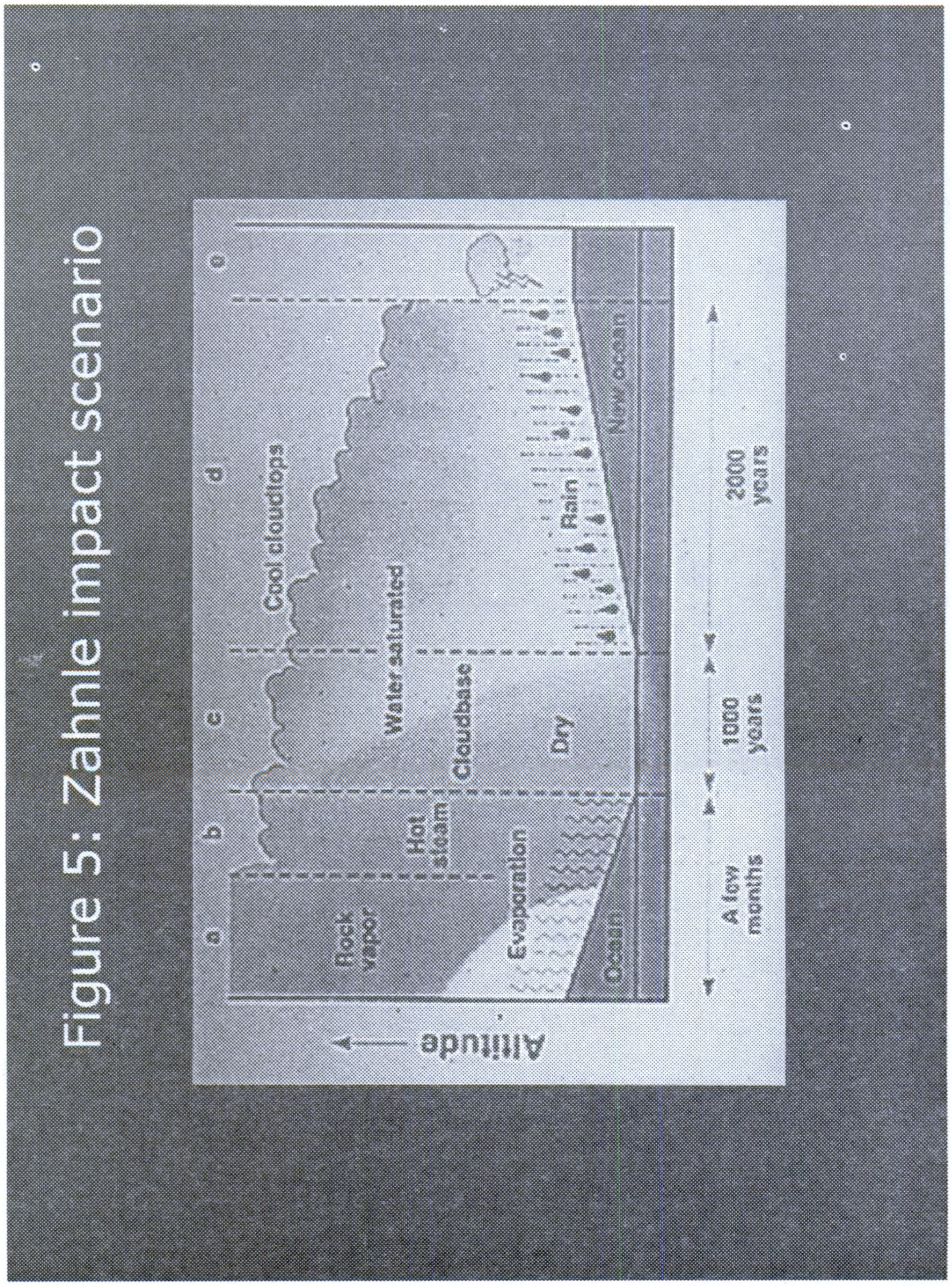


Figure 5: Zahnle impact scenario
Altitude
a
b
c
d
e
Rock vapor
Hot steam
Evaporation
Ocean
Water saturated
Cloudbase
Dry
Cool cloudtops
Rain
New ocean
A few months
1000 years
2000 years

Figure 6: Halobacteria in salt crystals

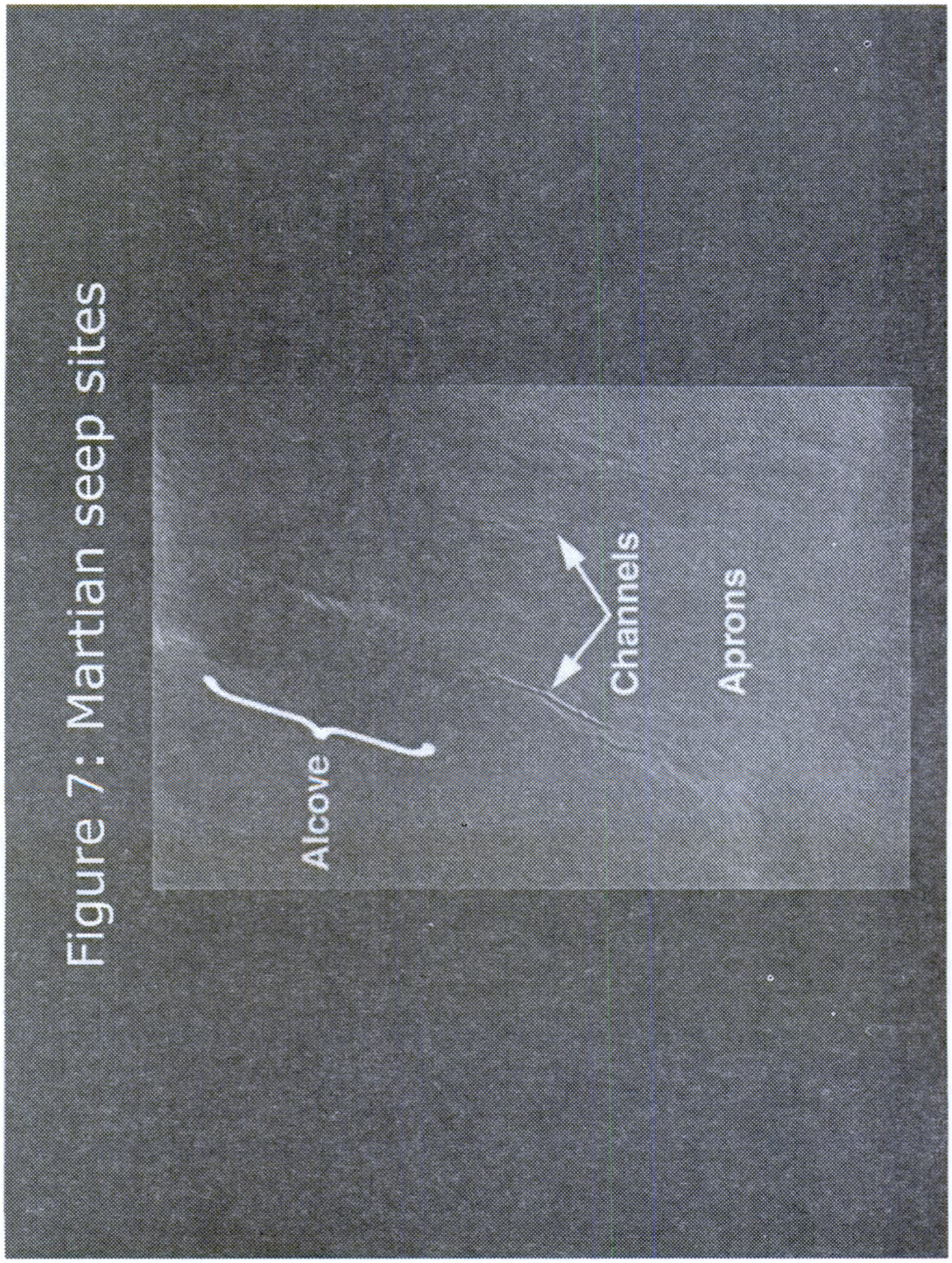


Figure 7: Martian seep sites
Alcove
Channels
Aprons

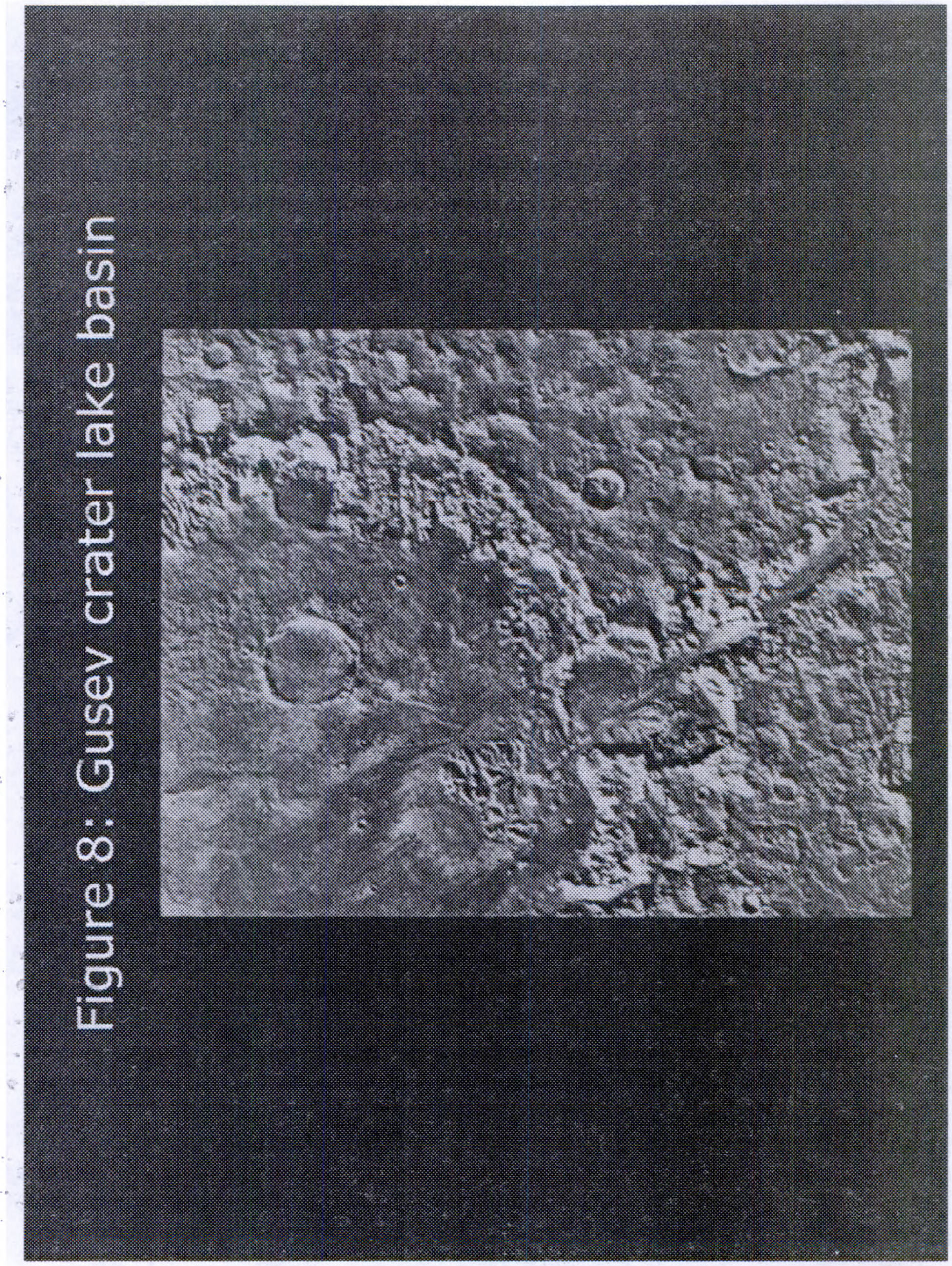


Figure 8: Gusev crater lake basin

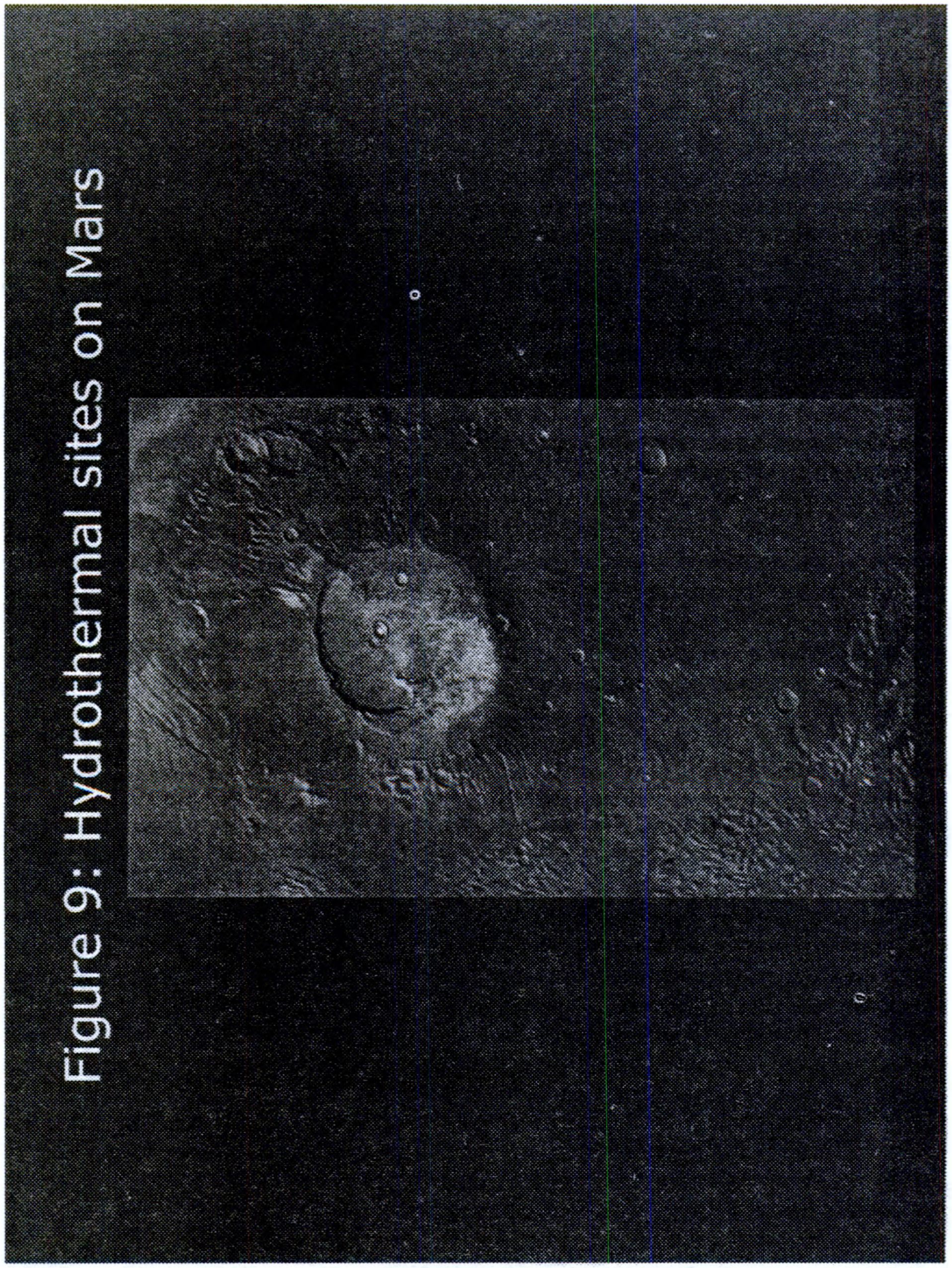


Figure 9: Hydrothermal sites on Mars

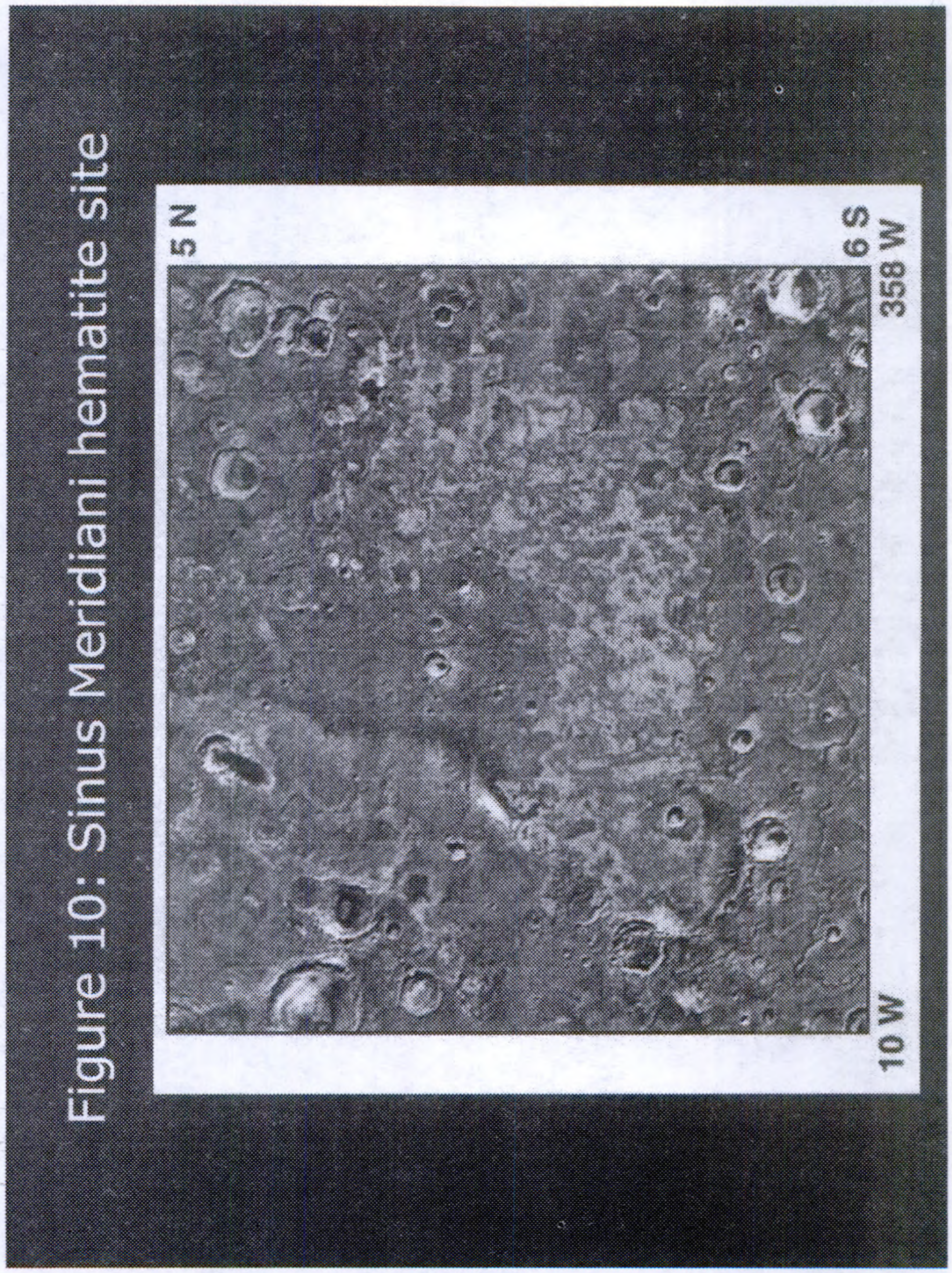


Figure 10: Sinus Meridiani hematite site

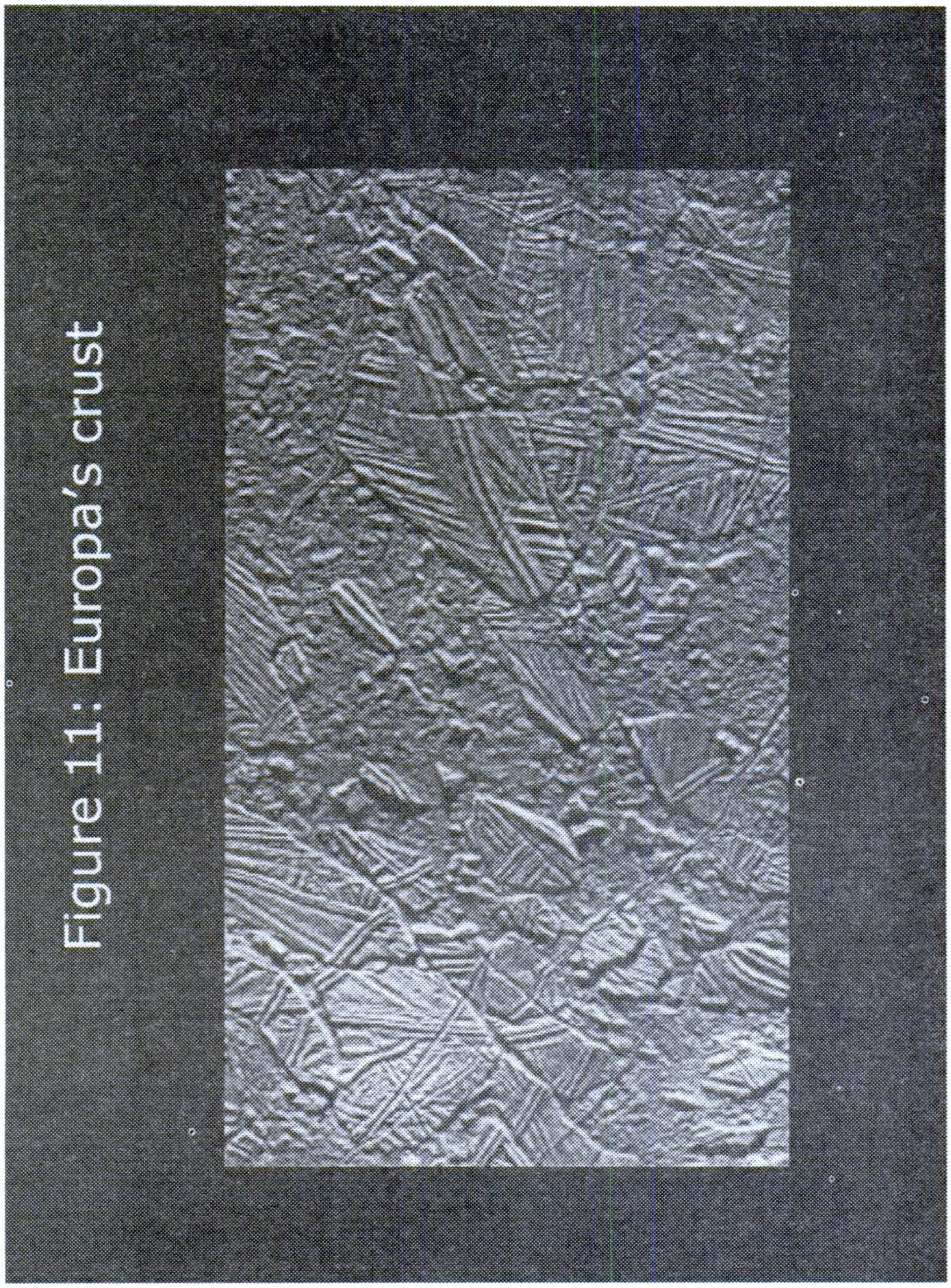


Figure 11: Europa's crust

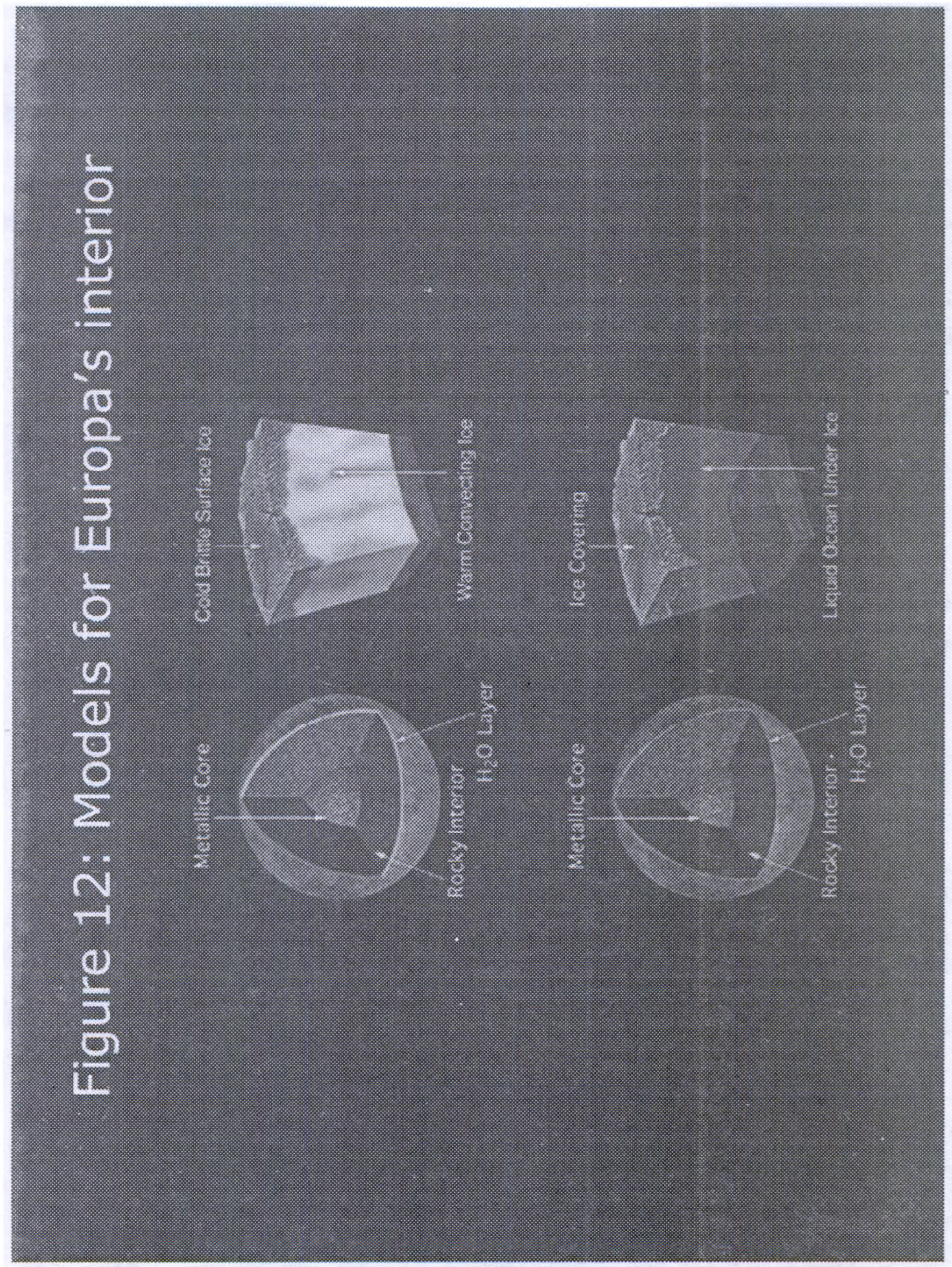


Figure 12: Models for Europa's interior
Metallic Core
Rocky Interior
H_2O Layer
Cold Brittle Surface Ice
Warm Convecting Ice
Metallic Core
Rocky Interior
H_2O Layer
Ice Covering
Liquid Ocean Under Ice

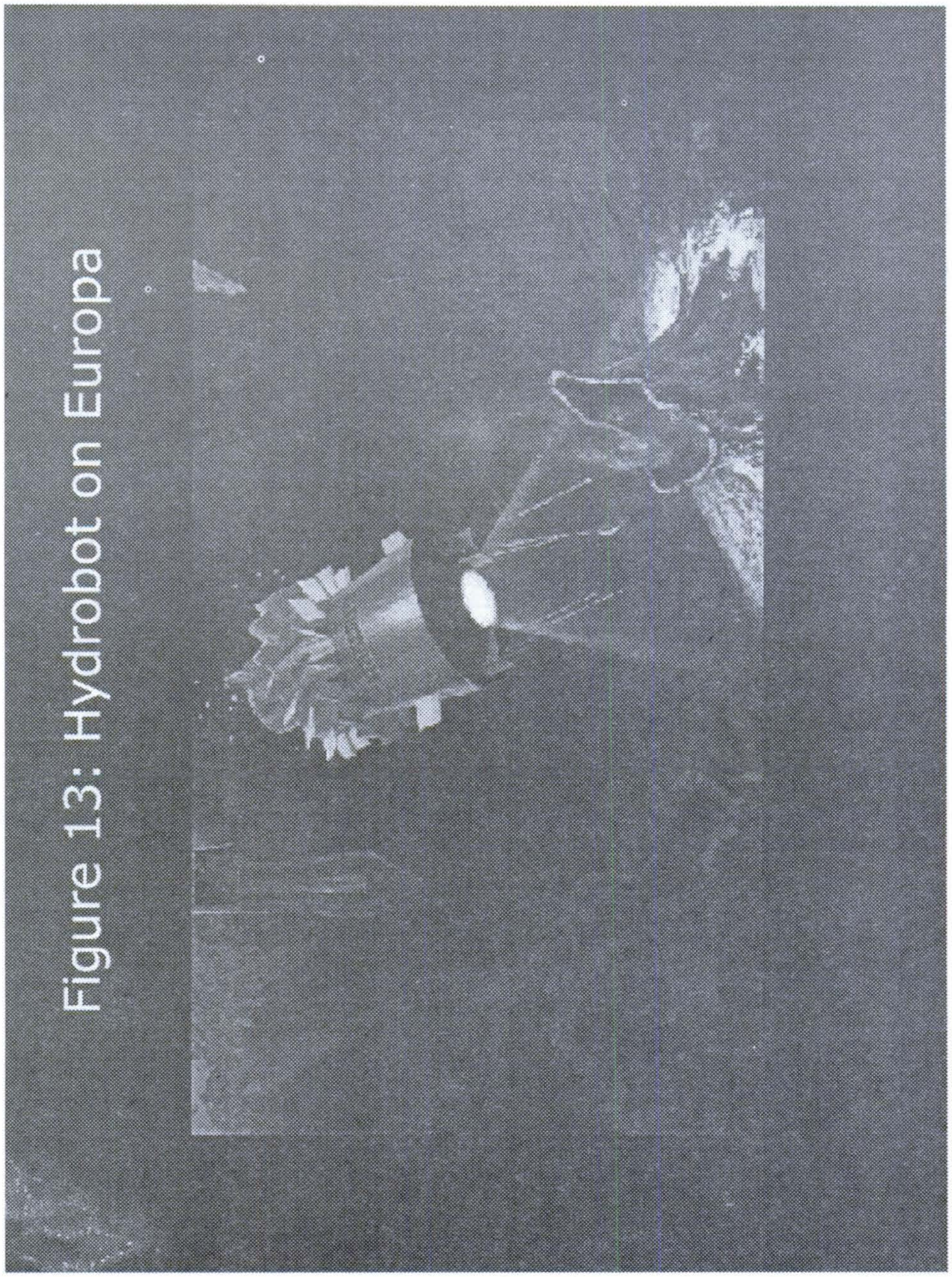


Figure 13: Hydrobot on Europa

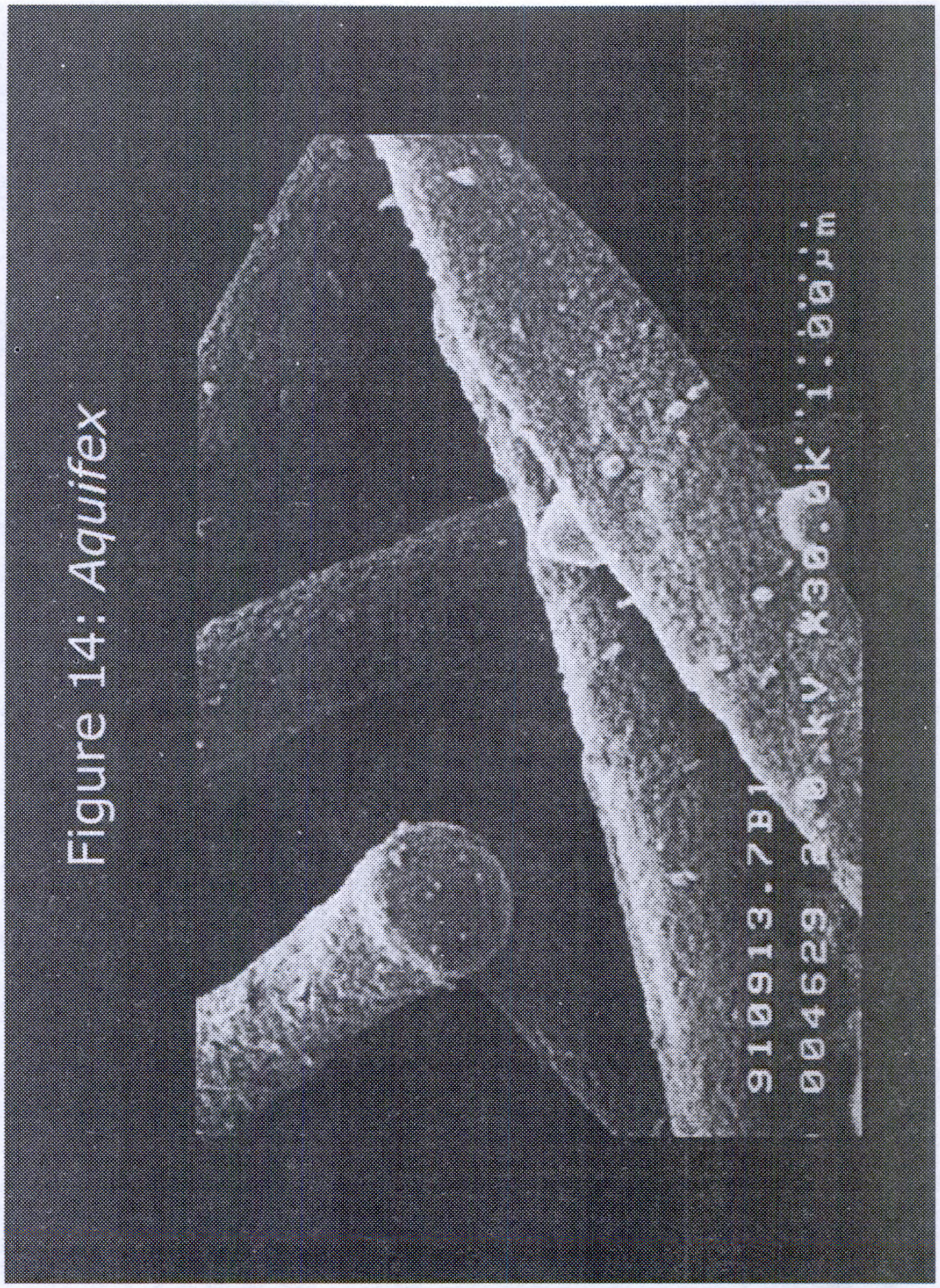


Figure 14: *Aquifex*


Figure 15: Martian lake beds?

Chairman ROHRABACHER. Thank you very much. So I guess when people come to us asking for money for space exploration, we should say, show me the water.

Mr. FARMER. Yeah.

Chairman ROHRABACHER. All right. What we should do now is have a break. We will come back right after the last vote. And I understand there will be—there might be two votes as usual, but there might be a procedural vote. So this Committee is in recess for probably around 15 minutes.

[Recess]

Chairman ROHRABACHER. We have certain elements that are common in the universe to life. And what was it that I heard once? It was the two most common elements in the universe are hydrogen and stupidity. All right.

This hearing is called back into order. Our next witness is Dr. Ed Weiler, NASA's Associate Administrator for Space Science. And it is good to see you again, doctor, and you may proceed with your 5-minute summary, but go right ahead.

STATEMENT OF DR. EDWARD J. WEILER, ASSOCIATE ADMINISTRATOR, OFFICE OF SPACE SCIENCE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

Dr. WEILER. Thank you, Mr. Chairman, and, members of the Committee, for affording me the opportunity to discuss what I consider to be one of the most profound questions in science—is there life beyond the earth?

We certainly can prove that life sprung up on at least one planet in the universe, our own earth. The question is, did this happen anywhere else. I will share my perspective on this question and then briefly summarize NASA's search for life beyond our own solar system.

First, we must ask—could we go back a slide? First, we must ask, are there other planets and solar systems where life could develop? As far as we know, you need a planet for life to develop. After Hubble—the Hubble Space Telescope was launched in 1990, we began to get growing evidence that, at least, the process to produce solar systems is common. This is a Hubble image of a protoplanetary—this is the Hubble image of protoplanetary disk with young baby stars at their centers.

In the 1980's—I am sorry—in the 1800's, a theory was put forth which proposed that our solar system formed from a cloud of dust and gas that condensed into a central star with a disk of gas and dust swirling around it. Through the process of accretion within that spinning disk, the planets then formed. What we are seeing here in these images is what our solar system probably looked like a few million years after it was born.

SEARCH FOR EXTRASOLAR PLANETS

But even 5 years ago, there was not one single shred of evidence for a planet outside of our own solar system. Just in the past few years, however, ground-based astronomers have obtained indirect evidence for the existence of actual planet-like bodies around other stars. Today, over 50 such objects have been found. Most are very large objects, in the Jupiter class, but this should be expected as these large bodies are exactly the type of planets that current technology can easily detect. So in other words, we shouldn't be disappointed they haven't found any Earths yet. The technology isn't there yet. Okay. Let us go to the next chart.

So we have found that the process to produce planets is common. We have even found Jupiter-like planets. But what are the possibilities that there are other Earths out there orbiting other Suns? To answer this question, I need to put our own Sun into its proper perspective.

This is one Hubble image of a tiny, but rich, portion of our own Milky Way Galaxy. There are literally thousands of stars in this one image that covers 1/200 millionth of the sky. Put that in human terms—take a sewing needle, a large sewing needle, go out at night, hold it up at the end of your arm and look through the hole at the end—in the sewing needle. That is the size of the sky this one picture represents. You would need 200 million of these pictures to cover the whole sky. Next chart, please.

This is a Hubble image of a typical galaxy like our own. It contains over 200 billion individual stars, most of them very similar to our own sun. And, finally, this is probably the most famous Hubble picture of all, the Hubble Deep Field. It is the deepest image ever taken of the universe in an exposure of over 30 hours. This image has literally hundreds of galaxies, some that are just forming a billion years or so after the Big Bang. This image also represents just that tiny sewing needle's view of the universe. It would take 200 million pictures like this to cover the universe. And, remember, this picture has hundreds of galaxies in it.

The bottom line—the bottom line is that there are literally tens of billions of galaxies in the universe, each containing hundreds of billions of stars. One calculation has estimated that the number of stars in the universe may exceed 10 to the 22nd power. That is 1 followed by 22 zeros stars. Since we know that the process to form planets around stars seems common, that other planets do exist outside the solar system, and we know that there are 10^{22} stars, what are the chances that there are a few Earths out there or perhaps a few thousands or millions or billions? How are we going to search for these Earths?

NASA'S FOLLOW-ON MISSIONS TO THE HUBBLE SPACE TELESCOPE

This is a picture of an artist's conception of the Space Interferometry Mission to be launched by NASA at the end of this decade. It will perform the first census of nearby solar systems. SIM will detect planets far less massive than Jupiter, like Uranus and Neptune, and perhaps as small as a few Earth masses. It will identify key target stars in their planetary systems for the cornerstone of NASA's Origins program, the Terrestrial Planet Finder, or TPF. TPF will launch in the middle of the next decade. Its sole purpose is to image Earth-like planets and, most importantly, to analyze their atmospheres for evidence of potential biology.

Here we have three spectra of Venus, Earth, and Mars. You will notice Earth is the only one that shows oxygen, water, and carbon dioxide. If we find those three elements in peaceful coexistence in the atmosphere of a planet, there is a very good chance that this indicates biology on that planet exists since that is what produces this combination in our own atmosphere. Note, only the spectra of Earth shows these three molecules. Larger and later versions of TPF could search for direct evidence of civilizations by looking for the effects of industrialized populations, such as lights at night, agriculture, industrial pollution, CFCs in the atmosphere.

This century, in my opinion, will be the period in human history when we can finally answer the question that has been around since the dawn of civilization: Are we alone in the universe? I personally believe that we will find that life is not a cosmic quirk, but a cosmic imperative. Thank you.

[The prepared statement of Dr. Weiler follows:]

PREPARED STATEMENT OF EDWARD J. WEILER

Mr. Chairman and Members of the Committee:

I am pleased to be here today to present to you "The Search for Earths Beyond Our Solar System".

The Questions Inspiring NASA's Origins Program: Are We Alone? Where are our Nearest Neighbors?

"There are countless suns and countless Earths all rotating around their suns in exactly the same way as the seven planets of our system. We see only the suns because they are the largest bodies and are luminous, but their planets remain invisible to us because they are smaller and non-luminous. The countless worlds in the universe are no worse and no less inhabited than our Earth."

These words, written in 1584 by Giordano Bruno, lay out the major challenge of NASA's Origins program, namely to use 21st century science to discover whether Earth-like planets exist beyond our Solar System and whether any of those planets are habitable or even inhabited by primitive life. The public and the scientific response to NASA's search for habitable planets and life has been considerably more enthusiastic than that of Bruno's contemporaries, who had him burned at the stake in 1600.

Most recently, the National Academy of Science's Decadal Review of Astronomy and Astrophysics endorsed these Origins goals, noting:

"Key problems that are particularly ripe for advances in the coming decade. . .[include] studying the formation of stars and their planetary systems, and the birth and evolution of giant and terrestrial planets."

"Search for Life outside of earth and, if it is found, determine its nature and its distribution in the galaxy. . .. [This] is so challenging and of such importance that it could occupy astronomers for the foreseeable future."

I will first summarize what we know about planetary systems based on present observational techniques and then lay out what we will learn in the coming decade as new NASA missions bring us a deeper knowledge about those most basic human questions: Are we alone? Where are our closest stellar neighbors?

Results from Indirect Measurement Techniques

The small tug of a planet on its parent star causes a small (only a few miles an hour) variation in the velocity of the star. This variation can be detected using a technique that measures the Doppler shift—the change in frequencies of the light when the star is moving toward us versus moving away from us. To date, we have found almost 75 stars showing significant Doppler variations; from these we have learned that approximately 7% of stars like the Sun have large planets located within a few Astronomical Units (the Earth-Sun distance, or AU) of their parent star. These large planets range in size from 0.2 Jupiter masses (M_J) to ~15 Jupiters. The data, much of it obtained using NASA-funded observing time on the Keck telescope, strongly suggest the existence of a larger number of still smaller objects just below the present limits of detection. Although masses measured with the Doppler technique suffer from an ambiguity related to the orientation of the orbital plane to the line of sight, the vast majority of objects detected to date are certainly much smaller than stars; most are gas giant planets similar to our own Jupiter or Saturn. The recent measurement of one object, detected by the Doppler technique, that happens to pass directly in front of its star as seen from Earth has shown definitively that this object is a planet with a mass slightly smaller than Jupiter's and with the density of alight, gas giant planet like Saturn.

While only a handful of systems with multiple planets are known, the Doppler data for more than half of the stars under study are highly suggestive of additional planets on more distant, longer period orbits. While multiple systems may eventually prove be common, as yet we know of no counterpart to our own "grand design" solar system with gas giants on circular orbits located beyond the water-ice condensation line and rocky planets nestled within the habitable zone. Furthermore, the broad range of eccentricities and small orbital radii of the known giant planets may be inconsistent with the stable conditions needed for the formation and survival of habitable, terrestrial planets. Some have argued that these unexpected results mean that solar systems like our own are rare. However, most scientists would respond that this is because the Doppler technique is fundamentally limited to finding massive planets on short period orbits. Before being discouraged about the prospects for finding other Earths, we should note that we do not yet have the observational capability to find systems like our own! Learning about the planets that may orbit the remaining 93% of solar type stars for which the Doppler technique has provided only upper limits is one of the Origins program's long term goals.

The Promise of Astrometry

I A second indirect planet-search technique looks for the positional (astrometric) wobble of a star induced by the presence of a planet. NASA has two complementary astrometric experiments aimed at planet detection: the Space Interferometer Mission (SIM) and the Keck Interferometer (Keck-I). SIM will have the exquisite sensitivity needed to detect planets of just a few Earth masses in 1–5 AU orbits around stars as far away as 30 light years. SIM will push the detectable mass limits for planets around the nearest stars into the range predicted for the "rocky" as opposed to "gas giant" planets. Keck-I will be less sensitive than SIM, but because it will operate for up to 25 years, Keck-I will be able to find planets as large as Uranus on long-period orbits. Together SIM and Keck-I will provide a complete and unbiased census of thousands of nearby stars to determine whether systems more similar to our own are the exception or the rule.

The Challenge of Direct Detection and the Terrestrial Planet Finder

While indirect techniques are very powerful at finding planets, the search for habitability and for life requires that we detect photons directly from planets and use spectroscopic analysis to learn about physical and atmospheric conditions. Thus, the goal of the Terrestrial Planet Finder (TPF) is to find and characterize any Earth-like planets orbiting ~250 of the closest (within 50 light, years) stars. This search will focus on the habitable zone (1 AU around a star like our Sun), which is defined by the range of temperatures where liquid water, and thus the conditions for the formation of life, might be present. TPF will make detailed observations of the atmospheres of the most promising candidates to search for the spectral signatures of habitability and of life. Understanding the conditions needed for life and identifying promising biosignatures requires a close and continuing collaboration with biologists, atmospheric chemists, and geologists. NASA's astrobiology scientists have been intimately involved in setting the observing requirements for TPF.

The technology to detect planets directly is within our grasp. The challenges include faint signals, the enormous contrast ratio between the star and the planet, the close proximity of the planet to the star, and the presence of dust emission in our own and in the target solar systems. The nature of these problems differs in the two wavelength regimes: reflected light in the near-IR and visible and thermal emission in the mid-infrared.

Visible Light Systems

i An observatory that can detect the light of a parent star reflected off of a distant Earth requires a large, visible light telescope (roughly the same 6–8 m size of the Next Generation Space Telescope, but with much better optical performance), equipped with an advanced coronagraph to block the glare of the star. The advantages of such a telescope include operation in a traditional imaging mode on a single spacecraft. The chief disadvantage arises from the extreme star-to-planet contrast ratio of more than one billion to one, which implies the need for exquisite control of the scattered and diffracted light. Spectral features of water and molecular oxygen could exist and be used to characterize a planet's atmosphere.

Infrared Systems

An observatory that can detect the emitted thermal radiation from an Earth requires a nulling infrared interferometer consisting of four small telescopes, each 2–3 meters in diameter. The telescopes would operate on separated spacecraft over baselines of ~100 meters to achieve the angular resolution required to separate the planet's light from the star's. The chief advantages of this system include the relatively favorable star-to-planet contrast ratio (only a million to one!) and the presence of very broad, deep bands of carbon dioxide, water and ozone that can be used to characterize the planetary atmosphere and serve as signposts of life. The disadvantages include the need for multiple spacecraft and cryogenic operation.

All of these options for direct planet finding (visible coronagraphs or infrared interferometers) are being investigated in the U.S. by four NASA-sponsored studies involving 16 industrial concerns, 30 universities and 75 scientists. These groups are investigating the broadest possible range of architectures for TPF. From a list of more than 20 concepts, NASA and its contractors have chosen 4 of the most promising for study. At the end of this year, NASA will select 2 architectures for intensive technology development over the next four years in preparation for a final choice of architecture and a new start around 2008, and a launch around 2014.

When the Galileo spacecraft flew by Earth on its way to Jupiter, the spacecraft turned its instruments toward Earth to look for signs of life. Other than the radio signals and the lights being on at night, the signs of life from Earth were surprisingly subtle. There was a complex green color on the continents (which we know are plants) and some chemicals carbon dioxide, oxygen, methane and nitrites coexisting in the atmosphere—a chemical impossibility unless maintained by something like life. But, Earth did not always have 20% oxygen atmosphere. Early Earth hosted a high-temperature non-photosynthetic biosphere, rich in carbon dioxide and poor in oxygen. Life on Earth was microbial and acquired energy consuming hydrogen and sulfide, producing a broad array of reduced carbon and sulfur gases. What chemicals would be identifiable signs of life in the early Earth's atmosphere?

The challenge to astrobiologists is to determine what biosignatures can be expected on any living planet. To this end, astrobiologists are studying microbial ecosystems in extreme environments here on Earth as microcosms of what might have been on early Earth and what may be possible on extrasolar planets.

A Step-by-Step Approach to NASA's Origins Goals

While the launch of TPF is more than a decade away, we are not standing still in terms of expanding our scientific knowledge. The results of earlier projects will help us to understand better the difficulty of the TPF challenge by finding out, for example, the distance to the nearest systems likely to harbor Earths and the amount of exo-zodiacal dust to expect:

- The Space Infrared Telescope Facility (SIRTF), the Keck Interferometer, the Large Binocular Telescope (LBT) and NGST will characterize zodiacal dust clouds around nearby stars. We will explore the links between these dust clouds and the presence of planets, as well as the potentially deleterious effects of these clouds on the ability to detect other "Earths".
- The Keck Interferometer and SIM will extend the census of planetary systems to planets with lower mass or on longer period orbits than are presently known from radial velocity studies.
- Studies funded by the NASA Astrobiology program (including the NASA Astrobiology Institute) and other programs will refine our understanding of the best markers of biological activity suitable for detection by TPF.
- In addition, NASA has just released a new research opportunity requesting proposals for studies of discovery-class missions that might serve as technology or scientific precursors to TPF. Such missions might include surveys for transits of planets orbiting distant stars or for the direct detection of giant planets around nearby stars.

In parallel with improving our scientific understanding in advance of TPF, NASA is working to ensure that the technology for TPF will be ready as well.

- The requisite technologies for the interferometric option for TPF are being developed and demonstrated on the Keck Interferometer, SIM, and Star Light projects.
- The large, lightweight telescope technology needed for either approach is being developed for NGST.
- Other technologies, including coolers, detectors, and precision wavefront control for coronagraphs, are being developed with an aggressive program funded as part of TPF.

We are also beginning to think about the next steps beyond TPF, including a "Planet Imager" to provide more detailed images and/or spectroscopy of any planets found by TPF. While we are still in the preliminary phases of conceptualizing such a mission, we must ensure that the Origins program as currently structured enables us to build toward this ultimate goal.

The Legacy of the Origins Program

What will be the legacy of NASA's Origins program as seen from 20 years in the future? We will have a complete census of the planets orbiting thousands of stars over a wide range of periods (from days to decades), planetary masses (from Jupiter's to Earth's), and distances (a few to a few hundred light years). We will have correlated these facts with the properties of the parent stars to develop a deeper understanding of the physical processes controlling the formation and evolution of planetary systems. From this information we will understand whether our Solar System and our Earth are common or rare. We will have identified what nearby stars, if any, harbor analogs to our solar system with its stable habitable zone. And, if we are lucky, we will have found one or more places where the complex physical and chemical processes we call life were able to develop. Assuming these successes, we also expect to be preparing for missions that will go beyond TPF. Through the NASA's Origins program, we are beginning to answer one of the longest standing questions in the history of the human intellect: Are we alone?

Chairman ROHRABACHER. Fascinating. Those were all galaxies and not solar systems, but galaxies. Our final witness is Chris Chyba, who holds a Carl Sagan Chair for the Study of Life in the Universe at SETI Institute in Mountain View, California, which is—and is an Associate Professor of the Department of Geological and Environmental Science at Stanford University. So we welcome you, Dr. Chyba. Please proceed.

STATEMENT OF DR. CHRISTOPHER F. CHYBA, SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE (SETI) INSTITUTE, AND ASSOCIATE PROFESSOR, DEPARTMENT OF GEOLOGICAL AND ENVIRONMENTAL SCIENCE, STANFORD UNIVERSITY

Dr. CHYBA. Thank you, Mr. Chairman. And it is a pleasure to testify to this Committee at such an exciting time for the scientific investigations into the prospects for life elsewhere. As the previous witnesses have testified, the last decade has seen an extraordinary rebirth in our understanding of the prospects for life elsewhere in the universe.

We have learned that carbon-based organic molecules are almost everywhere, that extra solar planets are abundant, that Earth has a deep biosphere. There might be more mass in organisms underground than in all the trees on the surface of the planet. The Mars Global Surveyor has returned evidence that water may have flowed recently on the surface of Mars. Perhaps most exciting of all, there is evidence for another ocean in the solar system below Europa's ice crust. And when I say an ocean, I really mean an ocean. Its volume may be twice that of all the water in the Earth's oceans. And, finally, the scientific search for extraterrestrial intelligence is about to be revolutionized.

MISSION OF THE SETI INSTITUTE

As you said, Mr. Chairman, I am here representing the SETI Institute, which is a private scientific research and education institute with about 120 employees. The mission of the Institute is to use scientific methods to investigate the nature and distribution of life in the universe. And research at the Institute is anchored in two centers. One, which my colleague, Dr. Jill Tarter, directs for SETI programs, and the other, which is the Center for the Study of Life in the Universe, which I have the pleasure of directing.

The SETI Institute, from its inception, has included research across the broad spectrum of astrobiology. And that is because if we want to understand the search for extraterrestrial intelligence, that has to be in the context of all the sorts of issues you see on this slide.

Our premier observing project for extraterrestrial intelligence at the institute currently is Project Phoenix. Phoenix picked up where NASA's SETI's program ended in 1994, after it was terminated by a Congress in the year of great concern over the Federal budget deficit. Project Phoenix employs the world's largest radio telescope. This telescope is the Arecibo telescope in Puerto Rico with a 1,000-foot dish. You can see some cars down there toward the bottom for scale. And Phoenix—the Project Phoenix uses that telescope to search the vicinities of nearby stars for artificially produced signals. The project costs about $4 to $5 million a year to run, and it is entirely privately funded.

The goal of Phoenix is to examine the 1,000 nearest sun-like stars for radio signals that could indicate the presence of technical civilizations. We search two billion frequency channels, 28 million channels at a time. We don't assume we know what frequency they would be broadcasting on. Phoenix so far has examined a bit over half of its target list of 1,000 stars since it began in 1995. But we compete for time on Phoenix with other radio astronomy programs, so we only observe for about 500 hours per year.

Allen Telescope Array

We are, therefore, trying to move the scientific search for extraterrestrial intelligence into a new realm. And that realm will—We will enter that realm when we finish the construction of the Allen Telescope Array, which we are currently designing and will construct in a partnership with the University of California at Berkeley. The Allen Telescope Array will be an array of about 350 specially designed low-cost antennas, about 18 feet in diameter each. This is an artist's conception, already a bit out of date. And it will be simultaneously used for SETI and other radio astronomical research because it can look at the sky with multiple beams simultaneously.

The Allen Telescope Array will allow the SETI Institute to examine the nearest million stars over the next couple of decades, compared with 1,000 that are being examined by Phoenix. The construction costs to the end of the project will be about $30 million. And because of the innovative technology in this project, that is only about 20 percent of the cost of a conventional radio telescope with the same collecting area. This telescope is made possible through generous grants from the Paul Allen Foundation and Nathan Myhrvold, the former Chief Technology Officer of Microsoft.

Mr. Chairman, I think it is important to understand how little of the galaxy we have observed so far. In this image, if you look at the tiny little blue dot in the center of the orange sphere—so right here—the blue dot, which is centered on our solar system, shows how far out we have looked with Project Phoenix so far, about 200 light years out. The orange sphere represents how far out we will look with the Allen Telescope Array. When we examine a million stars with that array, we will have looked at about 1/

1000th of 1 percent of the stars in our galaxy. The rest of this image shows to scale the galaxy—or rather a quarter of the galaxy. I think there is a common misperception that we have looked and looked and looked, but, in fact, we have hardly begun to look.

SETI PEER REVIEW FUNDING

SETI science and the SETI Institute are at the cutting edge of radio astronomy with these new telescope designs, and the technology developments we have underway will benefit radio astronomy of all kinds. But in conclusion, Mr. Chairman, I would like to say that we are concerned that the Congressional termination of the SETI program within NASA's budget in Fiscal Year 1994, seems to have left the perception among some agencies that the search for extraterrestrial intelligence is a field of science that is not to be funded even in the peer-reviewed context or partnered with even when it is to mutual advantage. We don't think this is an accurate perception, but perceptions can take on lives of their own.

Yet, at the same time, we think that the scientific search for extraterrestrial intelligence fits naturally within the fundamental questions at the heart of NASA's astrobiology roadmap, such as: Are we alone? And as the astrobiology program moves forward, the SETI Institute would welcome the opportunity to work with NASA to integrate the search for extraterrestrial intelligence appropriately into that program.

But let me be clear, I am not suggesting any earmarking of government funds for the search for extraterrestrial intelligence. The SETI Institute is completely confident in its ability to compete effectively under peer review conditions. All we are asking is the opportunity to do so with our SETI projects, just as we do with our Life in the Universe projects.

We also believe that the experience of the Allen Telescope Array demonstrates the potential benefits of public/private partnerships in this area. Our partnership with the University of California at Berkeley to build that telescope and to help use that telescope as a potential prototype for the design of the Square Kilometer Array, is a powerful example of how these public partnerships—public/private partnerships can move the technology forward that will benefit the entire radio astronomical community. We hope that the Federal Government, as well as state governments, will be open to those sorts of partnerships. Thank you, Mr. Chairman.

[The prepared statement of Dr. Chyba follows:]

PREPARED STATEMENT OF CHRISTOPHER F. CHYBA

It is a pleasure to testify at such an exciting time for scientific investigations into the possibility of extraterrestrial life. Over the past decade we've learned a great deal that makes the prospects for life elsewhere seem better than ever. But we want to remember that prospects are not proof, and it still remains possible that Earth is the only planet where life exists. That would seem extraordinary, and I doubt it's likely in a galaxy with 400 billion stars, but the honest answer is that we don't know yet. But what we can do is to use scientific exploration to try and find out.

The rebirth of exobiology

Over the past decade there has been a rebirth of the scientific study of life elsewhere in the universe—and for very good reasons:

We've learned that organic molecules, the sort of carbon-based molecules on which life on Earth is based, are abundant not only in our own solar system, but throughout the space between the stars. They are likely to be present in many solar systems. But we haven't observed in interstellar space an analogous variety of silicon-based molecules. So, through scientific observation, we've gotten a hint that the old science-fiction speculation about "silicon-based life" seems unlikely to hold up in the real universe. The chemistry of biology elsewhere seems more likely than ever to be the chemistry of carbon, as it is on Earth.

We're finally beginning to learn what other planets are out there. While we can't yet detect solar systems like our own—but that is coming—at a minimum we now know that planets themselves are not rare. My own suspicion is that just about every kind of solar system that could be out there will be out there—so that ours will prove to be neither common nor rare. It will merely be one of a wide variety of possibilities. But again, we're in the process of finding out whether this is in fact the case.

Within our own solar system, we have more and more evidence on other worlds for liquid water, an essential ingredient for life as we know it. Water seems to have flowed on the Martian surface in the geologically recent past, and there is now strong, though still indirect, evidence for a second ocean in our solar system beneath the ice of Jupiter's moon Europa. By a second ocean I mean exactly that; the evidence from the *Voyager* and especially *Galileo* spacecraft missions points towards an ocean whose volume is nearly twice that of all the Earth's oceans combined. Perhaps even more astonishing, there is now evidence for subsurface oceans under the ice of two of Jupiter's other large moons, Ganymede and Callisto. We've gone from thinking that Earth's ocean is unique to thinking that our ocean may be one of many. If we want to look for life in our solar system, the importance of Europa—the world where the ocean appears to be closest to the surface—can hardly be exaggerated.

We've also learned that Earth harbors a deep subsurface biosphere, and that the mass in microorganisms beneath our feet, reaching down miles underground, likely equals or exceeds the mass of all the organisms on Earth's surface, forests included. This is a dramatically different picture of terrestrial life than the one we experience daily, and makes speculation about subsurface life on Europa, or vestigial life on Mars seem much more credible. Our understanding of the Earth helps shape our thinking about other worlds, and vice-versa.

Finally, we're slowly learning more about the history of life on Earth, and the events that have led to the development of intelligence. We should remember in this context that several species of dolphin have bigger brains in comparison to their body size than did *homo habilis,* one of our tool-using ancestors. But we don't know whether the evolution of human-style technical intelligence is something that will prove to be incredibly rare or common. Addressing this question by studying the history of life on Earth is important, but there's another way to approach the problem: the scientific search for extraterrestrial intelligence (SETI). This search is about to enter a far more sophisticated realm, which I will describe in detail in this testimony.

The SETI Institute

The SETI Institute is a private scientific institute with about 120 employees, dedicated to research, education, and public outreach. The Institute was founded almost 17 years ago. Its mission is to use scientific methods to investigate the nature and distribution of life in the universe. Research at the Institute is anchored by two centers, each directed by the holder of an endowed chair. Dr. Jill Tarter holds the Bernard Oliver Chair, and directs SETI programs at the Institute. I hold the Carl Sagan Chair, and direct the Institute's Center for the Study of Life in the Universe.

The Institute also has substantial education and public outreach components, both informally in the form of hundreds of talks given by Institute scientists to audiences of all ages, and more formally in terms of curriculum development. For example, the *Voyages Through Time* project, funded by the National Science Foundation, is a one-year, high school integrated science curriculum focussing on evolution as an overarching theme. Everything evolves—changes over time—from the universe itself to humans and their technology. *Voyages Through Time* will begin national field testing in September. The Institute, together with the Astronomical Society of the Pacific, is also developing the education and public outreach program for NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA). These are but a few highlights.

The Center for the Study of Life in the Universe

The SETI Institute's Center for the Study of Life in the Universe comprises some twenty-five scientists pursuing research dedicated to understanding the origin, nature, and prevalence of life in the universe. Institute scientists study interstellar organic chemistry, planet formation, the search for extrasolar planets, the chemistry of life's origins, microbiology and life in extreme environments, planetary climatology and habitability, Mars and Europa, the role of impacts in the history of life on Earth and the future of human civilization, dolphin and humpback whale communication, and many other topics. Most of this work is supported by peer-reviewed grants, usually funded by NASA but sometimes by the NSF or other agencies, and published in the leading scientific peer-reviewed journals. I am pleased to be testifying alongside Dr. Jack Farmer, who is one of many astrobiologists at universities or NASA centers around the country who early in their careers were Principal Investigators at the SETI Institute.

Our experience has taught us that cross-talk among these very disparate disciplines, together in a single scientific institute, can be enormously valuable in advancing our understanding of life in the universe. Examples include the application of information theory developed for electromagnetic signals to analyzing dolphin communication (published in *Animal Behavior*), climate modeling applied to target selection in a search for extrasolar habitable planets (published in *The Astrophysical Journal*), or signal processing algorithms initially developed for SETI enabling the detection of Earth-sized planets with the proposed Kepler spacecraft.

Other research groups at the Center include Dr. Pascal Lee's annual expeditions to Devon Island in the Canadian Arctic, where in conjunction with NASA's Ames Research Center and others, he and his colleagues study the Haughton impact crater and its hydrothermal vents as Earth analogues to Martian geological features. Dr. Lee's team also conducts "exploration research," in which they test the robot and astronaut technologies (including spacesuit tests and time-lagged communications) that human explorers may eventually use in field work on Mars.

A final example of the breadth of work at the SETI Institute would be my own group's work on techniques to investigate the likely ocean beneath Europa's ice cover, and the prospects for life in that ocean. In the past two years, we have published our results in *Science, Nature,* and *The Proceedings of the National Academy of Sciences.* This work has also often involved close cooperation with NASA. In particular, from 1997 to 1999, I chaired the Science Definition Team for NASA's upcoming Europa Orbiter Mission, a mission to search for Europa's putative ocean, and to begin to set the stage for investigating the possibility of life on that jovian moon.

Life in the Universe and SETI

Why has the SETI Institute, whose name is an acronym for "The Search for Extraterrestrial Intelligence," from its inception included research across the spectrum of what is now called astrobiology? It is because only by understanding the many factors that make a world habitable, that determine whether life arises on that world, whether that life gives rise to intelligence, and whether that life develops technology, can we put the search for electromagnetic signals from extraterrestrial civilizations into a scientific context. We do not assume answers to these questions: worlds that can support life may or may not be common; life on such worlds may or may not arise often; that life may or may not develop multicellularity or intelligence frequently; and intelligence may or may not often lead to technology. But the scientific investigation of these problems is exciting and inspiring (most importantly to children and students) and helps humanity place itself in the universe. There is a continuum of scientific questions that extends from the formation of stars and planets to the development of technical civilizations, and the search for extraterrestrial intelligence is an integral component of the scientific investigation of that continuum.

Project Phoenix

Fiscal Year 1994 was a year of great concern over the federal budget deficit. As a result of this concern, the High Resolution Microwave Survey (HRMS), NASA's SETI project, was terminated by Congress. Special-purpose HRMS technology had been developed by the SETI Institute under a cooperative agreement award from the NASA Ames Research Center. After the closing of NASA's HRMS project, this technology was provided to the SETI Institute in the form of a long-term loan from NASA, so that the taxpayers would receive some return on the multi-year investment into the development of the special purpose receivers and signal processors. Using its own philanthropically raised dollars, the SETI Institute has subsequently doubled the size of this system, and substantially enhanced its capabilities.

This enhanced system is currently in regular use by the SETI Institute's Project Phoenix. Project Phoenix employs the world's largest radio telescopes to search the vicinities of nearby stars for artificially produced signals. To discriminate against human-caused radio frequency interference, Phoenix observes with two widely separated antennas, currently the 1000 foot diameter Arecibo telescope in Puerto Rico, the world's most sensitive radio telescope, and the 210 foot Lovell telescope at the Jodrell Bank observatory in the United Kingdom. Phoenix was previously deployed on the Parkes and Mopra radio telescopes in Australia, and the 140 foot telescope at the National Radio Astronomy Observatory in Green Bank, West Virginia coupled with the Georgia Tech Woodbury 30 meter antenna.

Project Phoenix costs between $4 and 5 million dollars a year to run. It has been and remains entirely privately funded, through donations to the Institute of many sizes but including very generous gifts from some of America's most visionary technologists, such as William Hewlett, David Packard, Gordon Moore, Paul Allen, and Barney Oliver.

Project Phoenix's goal is to examine the 1000 nearest Sun-like stars for radio signals that could indicate the presence of a technical civilization. Phoenix's "targeted search system" examines stars one by one across the frequency range of 1 to 3 Gigahertz, or wavelengths from about 30 centimeters down to 10 centimeter. These frequencies are chosen because they lie within the so-called "microwave window," the range of the electromagnetic spectrum where the background noise (think of it as static on a radio dial) throughout the galaxy is lowest. Any civilization in our galaxy that wishes to maximize the efficiency of its signaling (achieve the highest signal-to-noise ratio) will know about and possibly exploit this window for efficient broadcasting. Since we cannot know the frequency or frequencies within this window at which another technical civilization would choose to broadcast, we try to cover as many channels as our instrumentation will allow. In fact, the Phoenix dedicated multi-channel spectrum analyzer allows us to examine 28 million frequencies simultaneously. It's as if instead of turning your radio dial looking for any station you could find, you had an instrument that could check 28 million positions of the dial at the same time and alert you if there was a broadcast on any one of them. Actually, it's more complicated than that, because we allow the frequency to drift with time (as truly extraterrestrial sources should, due to planetary rotation) and we examine two senses of circular polarization simultaneously, doubling the number of channels observed. Each target star is observed 56 million channels at a time for five minutes, and then highly optimized, real-time computational methods developed by the SETI Institute to search that entire time-frequency space for patterns indicative of signals.

The thousand nearest Sun-like stars lie within about 150 light years of Earth. This is only a tiny fraction of the entire Milky Way galaxy, which contains some 400 billion stars and is 100,000 light years across. Another way of saying this is that Project Phoenix, even though it is the most advanced SETI search ever conducted, will only examine several stars out of every billion in the galaxy. Phoenix has been operating since 1995, and has to date completed its observations of a bit more than half of its targets.

Why so slow? Since SETI gets so much media attention, it is easy to get the mistaken impression that SETI researchers have searched the galaxy thoroughly, yet still found nothing. In fact we've only examined about one-billionth of the galaxy so far. One reason is that we are only able to observe at Arecibo for 500 hours each year. Arecibo is the world's most sensitive radio telescope, and SETI must compete for time against other high priority astronomical observations. To alleviate these limitations, the SETI Institute together with the University of California is designing and building a revolutionary new radio telescope called the Allen Telescope Array, which I will describe later in this testimony.

How do we know if a signal is artificial?

The first criterion that any signal must satisfy in order to be artificial is to have a very narrow spectral bandwidth [in fact, we look for bandwidths below about 1 Hz (Hertz, a measure of frequency equal to one cycle per second) in width]. This is another way of saying that the wavelength of the signal is extremely precise; this precision is one way of making a transmission highly efficient. Narrow-band signals pack a lot of energy into a small amount of spectral space. Many natural objects in the universe produce radio waves (including our own Sun), but no naturally occurring source in the universe is known that produces bandwidths thinner than 300 Hz. Any object producing extremely narrow bandwidth signals is either artificial or represents some previously entirely unknown coherent astrophysical phenomenon.

Project Phoenix detects narrow bandwidth signals all the time. Unfortunately, to date all of them have been proven to be interference from artificial objects created

by humans. To help deal with the problem of human caused interference, our computers compare detected signals with a database of all previous terrestrial and satellite interference transmissions detected in earlier observations. Any apparent detections that pass through this filter are then automatically re-examined by Arecibo and a second telescope in Jodrell Bank, England. If the second telescope also sees the signal, we know that it's real and not instrumental noise, or some technical problem with the Arecibo telescope, or due to local interference. Moreover, because Jodrell Bank is in a different place on the Earth's surface (which is rotating and moving through space), if the signal is truly extraterrestrial there should be a precisely calculable frequency shift between the signal measured at the two telescopes. If this exact shift isn't seen, then once again the source of the signal isn't extraterrestrial.

Because Project Phoenix handles so much data at once, the data analysis has to be automated, computationally efficient, and executed in real time. The vast majority of our computational time goes into eliminating artificial signals that turn out to be human interference. The problem of interference is getting worse and worse, but fortunately computer power is simultaneously getting better and better.

Finally, to give some sense of how sensitive our searches are, it's worth mentioning that we have for many years tested our system by using the signal transmitted by the Pioneer 10 spacecraft, launched from Earth in 1972 and now traveling beyond our Solar System. Pioneer 10 is at a distance of 6 billion miles from Earth and broadcasting with a power of a few watts—much less than a light bulb in your house, but about the power of a small flashlight. It takes more than 10 hours for Pioneer 10's radio signal, traveling at the speed of light, to reach Earth. Because Pioneer 10 really is an extraterrestrial (even extra-Solar System!) artificial source, it provides an excellent test for our system—and it comes in loud and clear. (Or at least it did until last summer, when on-board antenna pointing connections were not successfully executed. Pioneer 10 can still be detected, but only after it receives a transmission on which to lock.)

SETI 2020

In 1997, the SETI Institute established a Science and Technology Working Group to examine future opportunities for SETI and make specific recommendations for how the discipline should proceed as Project Phoenix neared completion. The Working Group was composed of respected astronomers, physicists, SETI scientists and innovators from Silicon Valley and other high-technology firms. The Working Group conducted four 3-day meetings over a period of two years, resulting in a SETI science and technology plan for the years 2000 to 2020. Its report is being published by the SETI Institute under the title *SETI2020.*

The Working Group recommended that the SETI Institute: (1) Undertake the development and construction of an innovative 1 hectare (10,000 square meter) radio telescope to carry out targeted searches of candidate stars; (2) Begin studies of a second telescope that would be dedicated to an all-sky survey; and (3) Set aside funds for small-scale experiments to detect very rapidly pulsed infrared and optical signals of extraterrestrial origin using existing telescopes (so-called "optical SETI," which is just becoming possible due to our ability now to inexpensively detect laser pulses of only a billionth of a second duration). The SETI Institute is pursuing all three of these projects, and is already well along the way of prototyping the one hectare telescope, previously known as the 1HT but now being built as the Allen Telescope Array.

The Allen Telescope Array

Following the recommendations of the *SETI2020* report, the Allen Telescope Array (ATA) will be an array of about 350 specially designed, low-cost antennas, each 6 meters (18 feet) in diameter, that can be simultaneously used for both SETI and other radio-astronomical research. Because it will be able to observe many SETI target stars at the same time, with more channels (and from 1 to 10 GHz) and for 24 hours a day, the ATA will permit the SETI Institute to examine the nearest 100,000 or even million stars over the next two decades, compared with the 1000 observed by Project Phoenix. This means that we will be probing about ten times farther out into the galaxy. It should be remembered, though, that even a million stars still represents only a tiny fraction of the 400 billion stars in the Milky Way Galaxy. The ATA represents a huge step forward in SETI, but it will still remain the case that only a tiny fraction of the galaxy will be thoroughly examined.

The Allen Telescope Array was made possible by the far-sighted benevolence of technologists Paul Allen (co-founder of Microsoft) and Nathan Myhrvold (former Chief Technology Officer for Microsoft). It is a joint effort by the SETI Institute and the University of California, Berkeley (UCB), and will be built at the existing Hat

Creek Observatory, run by UCB, in northern California's Cascades. The ATA is scheduled to become partially operational in 2004 and fully operational in 2005. It is on time and on budget; with total estimated cost through construction of approximately $30 million, about 20% of the price of a conventional radio telescope of the same collecting area.

Until now it was only practical to construct the collecting area for a major radio telescope as single enormous dish, as at Arecibo, or as several large dishes (the Very Large Array in New Mexico has 27 dishes) whose output is combined. But the ATA will be constructed using hundreds of mass-produced dishes. By incorporating innovative technologies, miniaturized electronics and vast amounts of computer processing, the ATA will be able to observe up to a dozen SETI target stars simultaneously, over a wide range of simultaneous frequencies. It will also simultaneously be a premier instrument for more traditional research in radio astronomy. We have entered a realm where SETI research is driving telescope technology, and resulting in innovative cutting-edge designs that will further the research of more traditional, government-funded astronomers, and will alter the way that future facilities are built.

What happens if we detect a signal?

With Project Phoenix ongoing, and the Allen Telescope Array set to expand the number of stars observed by a factor of 100 to 1000, it is important to ask what happens should the search succeed.

In fact, scientists such as the SETI Institute's John Billingham and Jill Tarter have taken the lead in planning for the day we might receive a signal from life beyond Earth. Working with diplomats and space lawyers, they have helped develop protocols that guide the activities of SETI scientists if they think that they may have detected extraterrestrial intelligence. These protocols were adopted by the International Academy of Astronautics and the International Institute of Space Law. They are designed to emphasize confirmation and prevent a mistaken announcement. Perhaps above all, they promise that there shall be no secrecy. The SETI Institute symbolizes this commitment via its continuing live web-casting of its Project Phoenix observing sessions at Arecibo.

As in other areas of science, confirmation involves bringing other scientists into the investigation, who can observe the signal with other instruments, and perform a kind of "peer review" of the data and its interpretation before a public announcement is made. Once the observation is confirmed, an announcement would be made to the general public and the wider scientific community. Realistically, however, the press may well pick up the story long before final verification is made. It is important to avoid making premature—and therefore misleading—announcements to the public, but it is just as important to provide accurate information with some assessment of scientific uncertainty. SETI investigations are in some respects similar to those for Earth-crossing asteroids. The asteroid observing community has learned over the past decade the importance of taking extreme care with public announcements to ensure that misinterpretation and hype did not result when substantial scientific uncertainty was still present.

Beyond the immediate post-detection decision-making, there could be important social and philosophical implications of a detection of a signal. The SETI Institute also sponsors research into these questions. The Institute's SETI Press has published the book *Social Implications of the Detection of an Extraterrestrial Civilization,* based on a series of workshops on the cultural implications of SETI held in 1991 and 1992. Moreover, the Institute has on its staff a social scientist who studies these issues full time, Dr. Douglas Vakoch. Dr. Vakoch's work draws on his formal background in several areas, including Comparative Religion, History and Philosophy of Science, and Clinical Psychology. He applies insights from these disciplines to SETI by showing that in the same way that theologians, philosophers, and psychotherapists can expand their views by becoming more open to alternative perspectives, so too might humankind as a whole expand its world view by receiving messages from extraterrestrial civilizations.

Even though signals may be detected, it is unlikely that an interstellar dialogue would occur, except over extremely long timescales. If we detect a signal from a star 100 light years away, that message was sent 100 years ago—so that two-way communication would require 200 years for each reply. But human history has shown that the transmission of knowledge across great distances in time can still have profound effects; one need only consider the impact on medieval western Europe of the transmission of ancient Greek learning and science via the translation of Arab texts. The MIT physicist Phil Morrison has suggested that an extraterrestrial message would constitute "the archaeology not of the past, but of the future."

But it is quite possible that, while we could detect the signal's carrier wave, we would not have the sensitivity to detect whatever message might be carried by that wave. Even if we could, it is difficult to predict how difficult decipherment might prove to be. The metaphor of ancient Greek knowledge is an optimistic one. My personal expectation is that decipherment would prove very difficult. A possible better analogy could be the decipherment of inscriptions left by the ancient Maya, which proved extremely difficult. Even in this case, we had the advantage of being able to apply linguistic knowledge from extant Maya languages. And of course, we share a genetic and sociological heritage with any other human culture that we will not share with an extraterrestrial civilization. Nevertheless, if we detect an extraterrestrial radio signal, we will at least have in common the physics and mathematics that made that transmission possible, and this could be a starting point.

SETE public interest and scientific peer review

The scientific Search for Extraterrestrial Intelligence obviously enjoys great public interest. We see this every day at the Institute, where we serve as a resource for the press covering topics across the range of life in the universe studies. Our web site (*www.seti.org*) receives about two million hits per month. When I teach my graduate seminar, "The origins of life in the solar system" at Stanford every year, with students from a half-dozen different departments, every year the students enthusiastically request a visit to the SETI Institute to learn about Project Phoenix and the Allen Telescope Array. We view this kind of interest as a tremendous opportunity to teach students and the general public about science and the scientific method—that blend of openness to new ideas coupled with an insistence on hard evidence and skeptical analysis of data.

SETI is respected within the scientific community. One indication of this is the membership of the SETI Institute's Board of Trustees, which includes three members of the National Academy of Sciences: Frank Drake, Sandra Faber, and W. Jack Welch. A second indication comes from the "decadal review" of astronomy and astrophysics that the National Research Council (NRC) of the National Academy of Sciences conducts every ten years to survey the field and make recommendations for new research initiatives. Each of the past four decadal reviews conducted by the NRC has endorsed SETI. The most recent decadal review, *Astronomy and Astrophysics in the New Millennium,* reads (pp. 131–132):

> "Are we alone in the universe? Finding evidence for intelligence elsewhere would have a profound effect on humanity. Searching for evidence for extraterrestrial life of any form is technically very demanding, but, as indicated in the discussion of TPF [Terrestrial Planet Finder] above, there is a clear approach for doing so. The search for extraterrestrial intelligence is far more speculative because researchers do not know what to search for. Radio astronomers have taken the lead in addressing this challenging problem, and SETI programs are under way at many radio telescopes around the world. This [NRC] committee, like previous survey committees, believes that the speculative nature of SETI research demands continued development of innovative technology and approaches, which need not be restricted to radio wavelengths. The privately funded 1HT [now the Allen Telescope Array], which will be the first radio telescope built specifically for SETI research, is a good example of such an innovative approach, and it will pioneer new radio techniques that could be used in the SKA [Square Kilometer Array]."

The Square Kilometer Array

The Square Kilometer Array (SKA) is an international ground-based radio telescope that will have a million square meters of collecting area—making it a factor of 100 times more sensitive than the most sensitive existing radio telescopes. The National Academy's last decadal review endorsed a technology development program for the SKA, for the "unprecedented images" and "great discovery potential" that it will allow. The SKA is a big part of the future of radio astronomy, and the SETI Institute's Allen Telescope Array is pioneering techniques that could be used in the SKA. In effect, it is the leading prototype for the SKA.

SETI scientists are playing crucial roles in the planning for the SKA. My colleague Dr. Jill Tarter is Chair of the U.S. SKA Consortium, and Vice Chair of the International SKA consortium. Dr. Frank Drake, President of the SETI Institute, is the treasurer of the U.S. SKA consortium. Along with UC Berkeley, the SETI Institute has just hosted the current international conference on the SKA.

SETI and Astrobiology

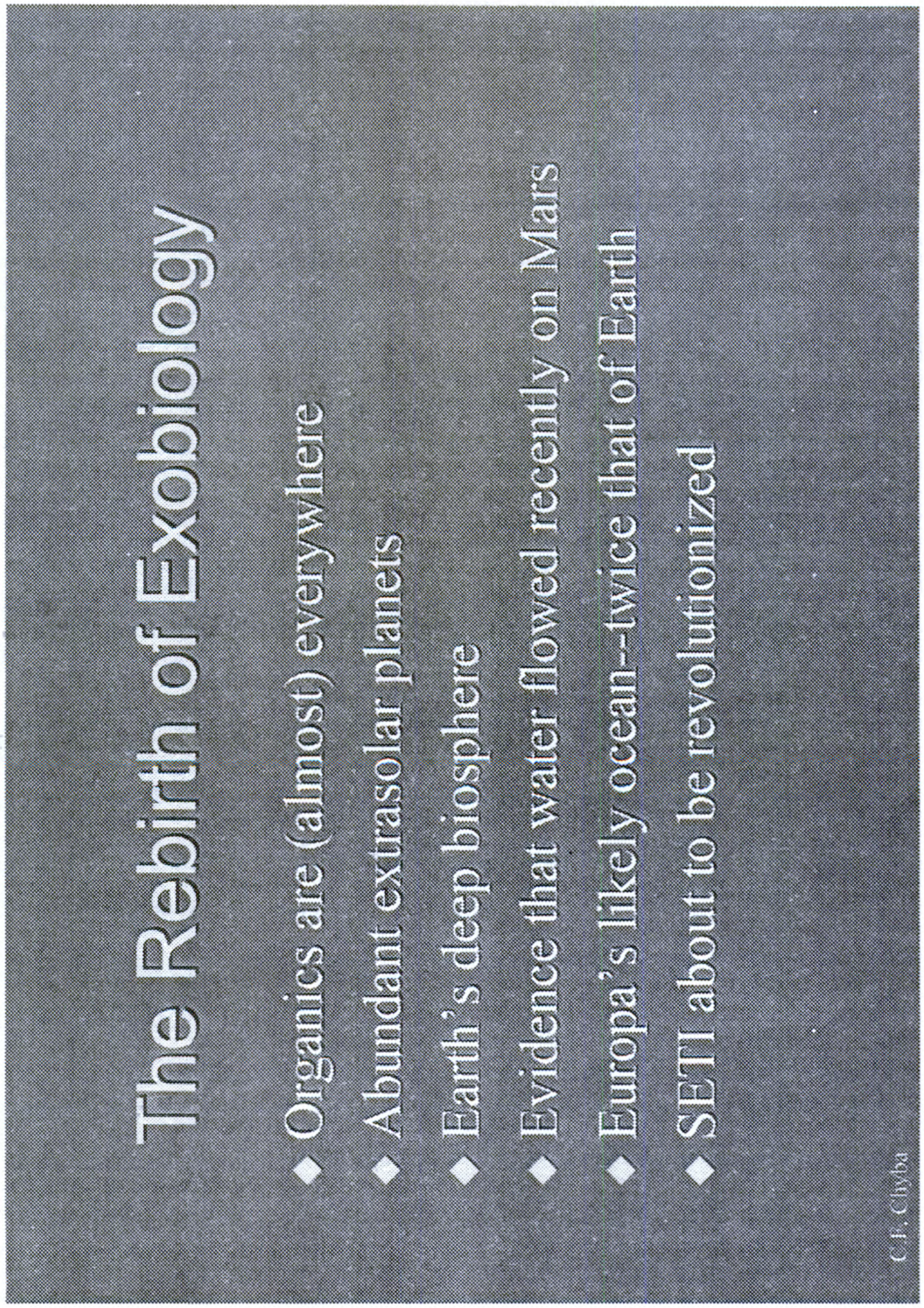
I hope that my testimony makes it clear that the scientific search for extraterrestrial intelligence is an integral part of the continuum of questions asked by astrobiology. SETI science and the SETI Institute are at the cutting edge of current radio astronomy, and the technology development underway will benefit radio astronomy of all kinds. Similarly, the distributed computing pioneered by the University of California's *SETI*@home project helped to kick-start the distributed computing industry. Finally, the science of SETI, while undeniably speculative, has repeatedly passed "peer review" within the scientific community, as shown by its endorsement in each of the last four astronomy and astrophysics decadal reviews by the National Academy of Sciences.

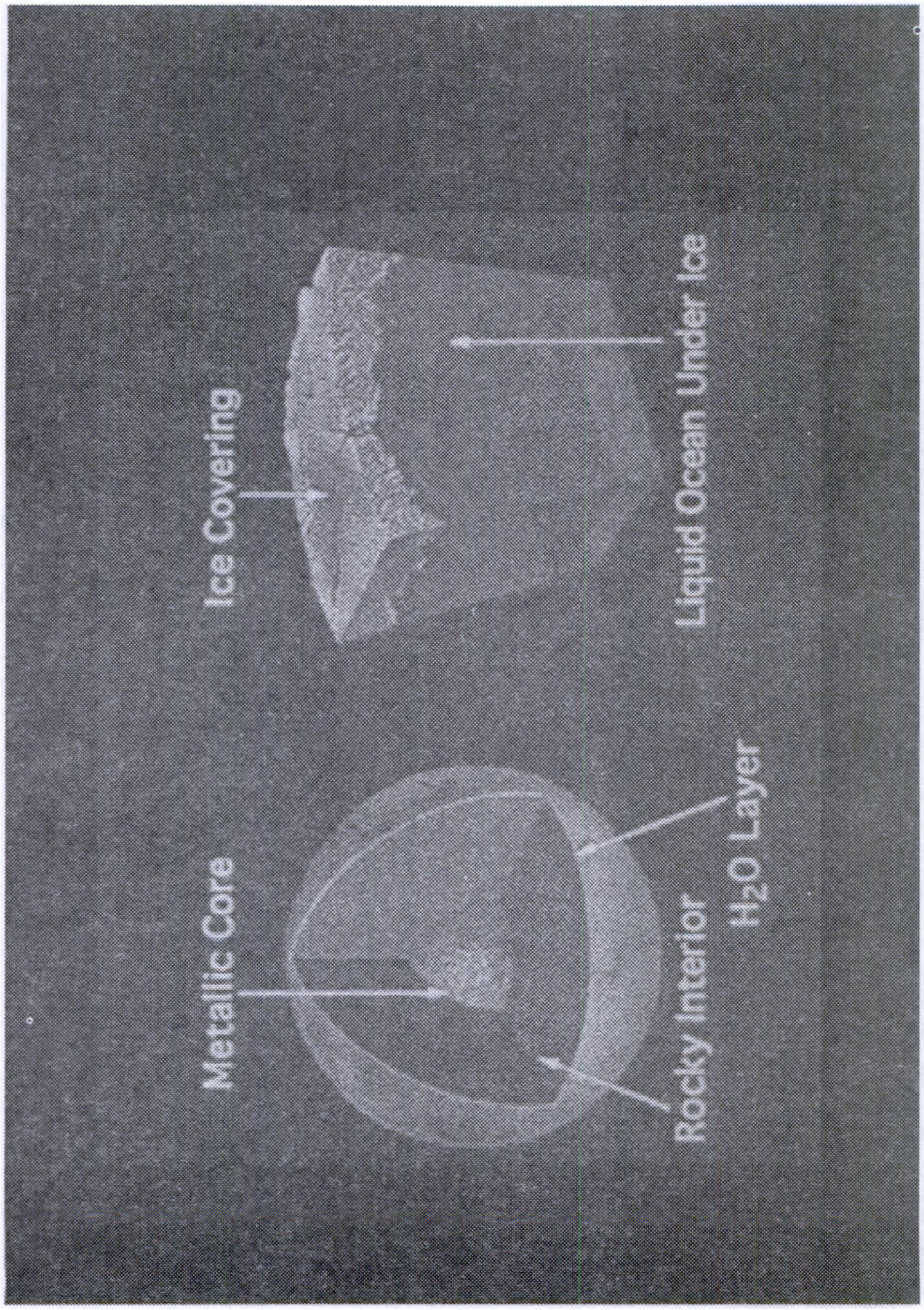
However, we are concerned that the search for extraterrestrial intelligence, despite having passed scientific peer-reviewed and being technologically cutting-edge, may not be competing on a level playing field within the federal government. The termination of the SETI program within NASA's budget in FY94 seems to have left the perception that the search for extraterrestrial intelligence is a field of science that may not be funded or partnered with. We do not think that this is an accurate perception but perceptions can take on a life of their own. While some opponents caricatured SETI in the 1993 Congressional debate, and called it a "project that really only helps just bureaucrats at NASA," others emphasized that they were not questioning its scientific value, but were acting in the face of the budget deficit.

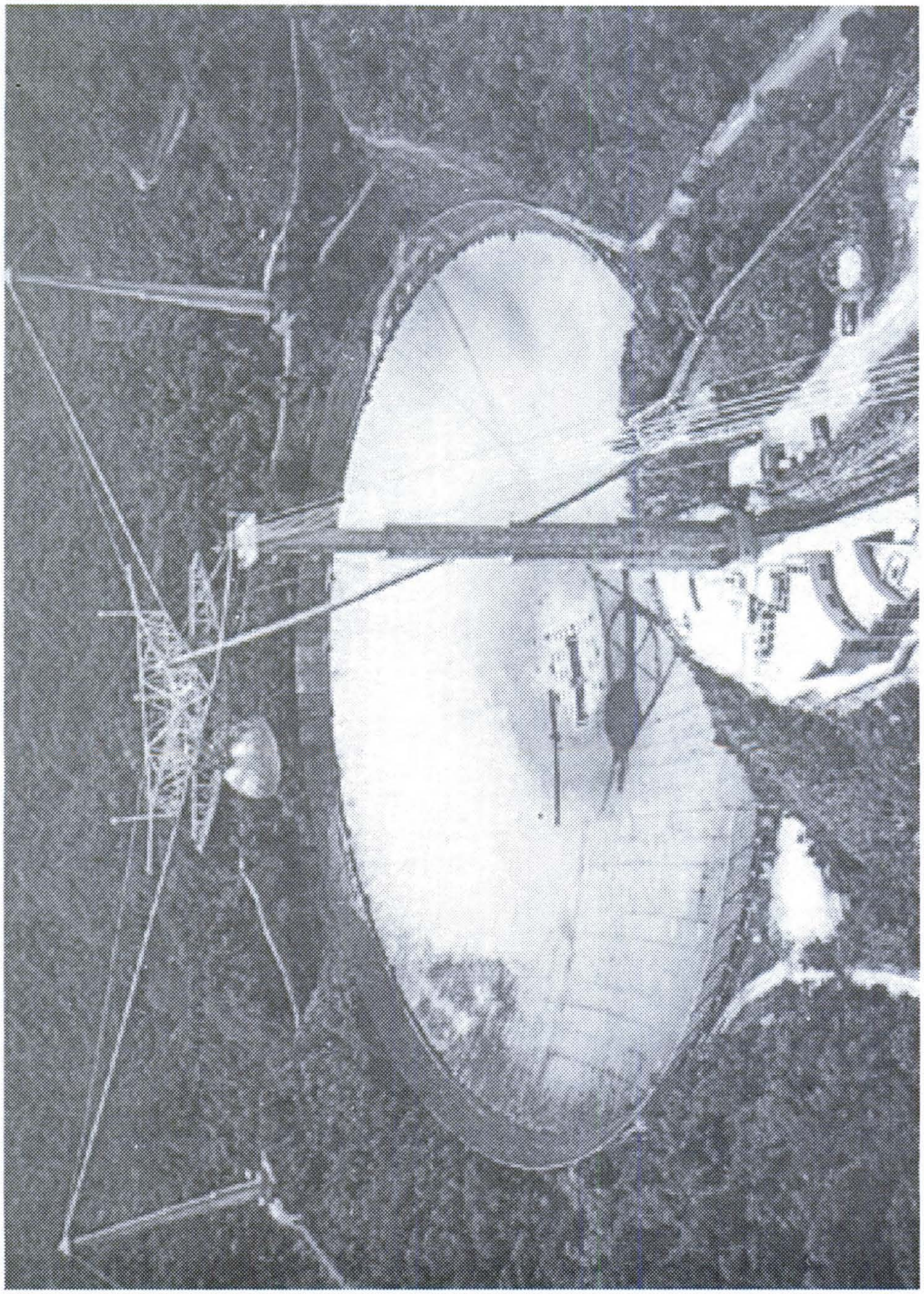
We think that SETI fits naturally with the fundamental questions at the heart of NASA's Astrobiology Roadmap. The Roadmap addresses three questions, including "Does life exist elsewhere in the universe?" (which is sometimes followed by the additional question "Are we alone?") and "What is life's future on Earth and beyond?" The question of whether any other intelligent civilizations exist elsewhere in the universe is a natural part of these questions. As the Astrobiology program moves forward, the SETI Institute would welcome the opportunity to work with NASA to integrate the search for extraterrestrial intelligence into this program.

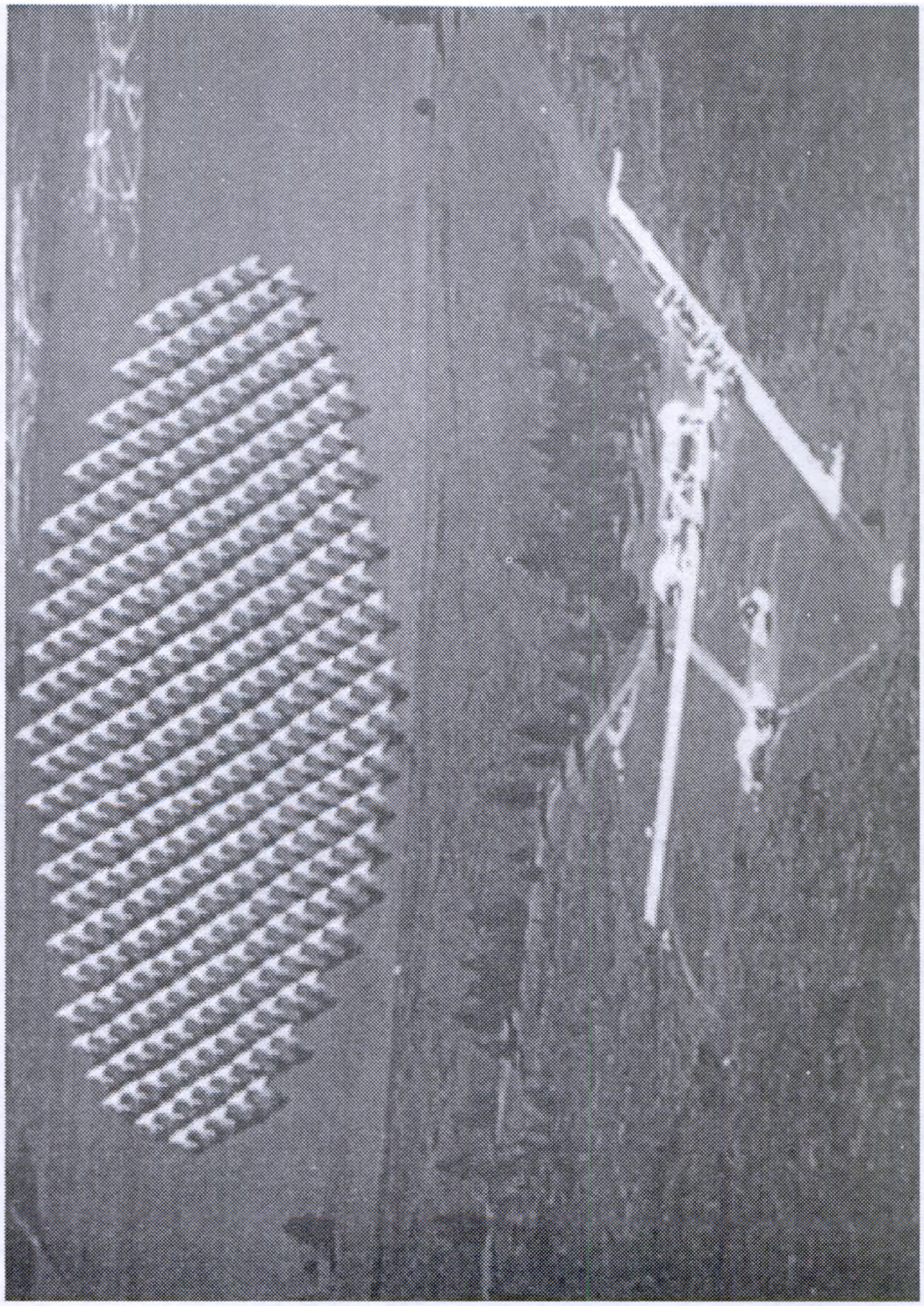
But let me be clear: I am not suggesting any earmarking of government funds for the search for extraterrestrial intelligence. The SETI Institute is completely confident in its ability to compete effectively under peer-review conditions, and we are obviously being successful in our private fund-raising. Our "life in the universe" projects—which cover all areas of astrobiology except for the search for extraterrestrial intelligence—compete for NASA and other federal grants routinely and successfully, and we are sure that SETI-related proposals would do so as well.

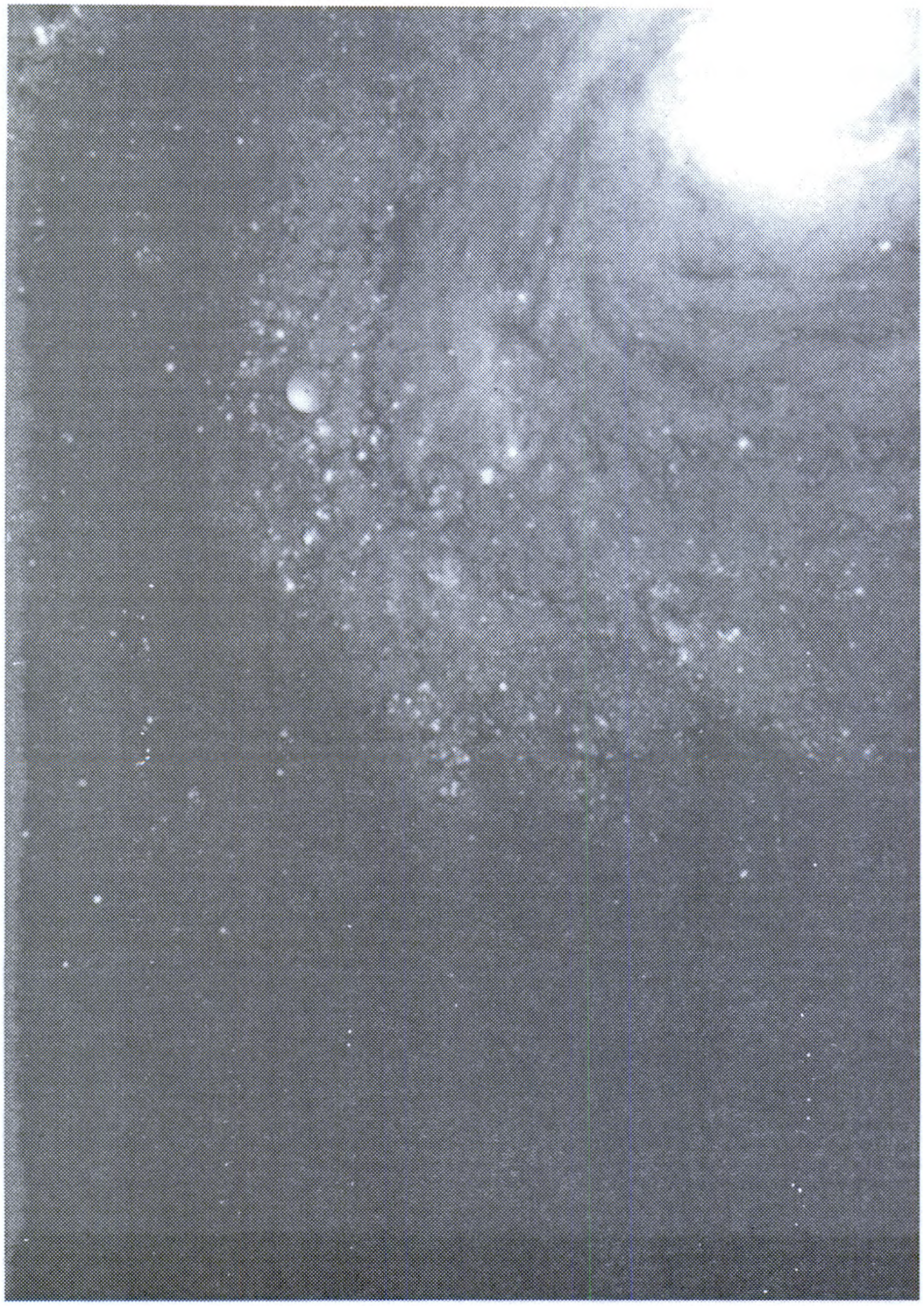
We also believe that the experience of the Allen Telescope Array demonstrates the potential benefits of public-private partnerships in this area. Our partnership with the University of California at Berkeley to build the ATA and to help plan the Square Kilometer Array is a powerful example of an extremely successful private-public partnership between the SETI Institute and the State of California. We hope that the U.S. federal government will be open to such partnerships as well. We believe that they will prove of mutual benefit, as they have already proven to be in the case of the Allen Telescope Array and the Square Kilometer Array. We would welcome the opportunity to discuss such opportunities further.


The Rebirth of Exobiology
◆ Organics are (almost) everywhere
◆ Abundant extrasolar planets
◆ Earth's deep biosphere
◆ Evidence that water flowed recently on Mars
◆ Europa's likely ocean–twice that of Earth
◆ SETI about to be revolutionized
C.F. Chyba


Metallic Core
Rocky Interior
H_2O Layer
Ice Covering
Liquid Ocean Under Ice







Chairman ROHRABACHER. Well, thank you. And I am impressed with what you have been able to accomplish since Federal funds were cut off. And that is very impressive, and it speaks well of your organization, and also it speaks well of your purpose as well as your structure. So, thank you very much and we wish you luck and we will see what—after we go through all these budget processes after a number of years and sift out what the Federal Government is going to be spending money on and what it shouldn't be spending money on, we will—that determination will be made whether or not some money will be going back in that direction or not. But put it this way, you are—you seem to be succeeding without it and I know that is not what you are here to testify about, but sometimes success is a problem as well as something to sing praises about.

Anyway, I am going to hesitate to ask questions and what I am going to do is start with Lamar Smith and let my——

Mr. SMITH. Mr. Chairman, thank you very much. On the way to asking a couple of questions, to Dr. Chyba, I would like to comment on some of the other testimony that we have heard. And first of all, I agree with Dr. Tyson about the immense public interest in the subject of astronomy and astrobiology. Whether it is the cover stories of a number of magazines, for instance, that you held up, Dr. Tyson, or whether it is articles that are well-positioned in newspapers on an almost daily basis. We saw page 2 of the Washington Post today mention the discovery of water and comets outside our solar system. First time that has ever occurred. There is a great deal of public interest in this subject. And I agree with you, Dr. Tyson, that the funding should match the public interest, and I don't believe that it does today. So I appreciate your bringing that point out.

Dr. Farmer, you mentioned the likelihood of discovery of microbes. We are on the verge of that. I agree with you on that. I am slightly envious of that T-shirt you mentioned wearing on the airplane. If you have any extra, I would be happy to talk to you about the appropriate size.

Dr. FARMER. And, actually you can order them over Lands—from Lands End over the web now. So——

Mr. SMITH. Lands End. Good. By the way, I have been looking for a couple of years for a tie with stars on it. If you know where I can get that, let me know as well.

Dr. Weiler, I actually do have a question for you, a brief question. I love the fact that you showed today the photograph of the deep field. I have that photograph on the wall of my office, and I oftentimes have mentioned it in town meetings. But I use a little different analogy than you do about the size of the dark spot in the heavens being seen through the eye of a needle. If I am at a Republican group, I talk about it as the size of the eye of Lincoln on a penny held at arm's length, and if I am at a Democratic group, I talk about the spot of sky covered by the eye of Roosevelt on a dime. But, in any case, the point is the same and the photograph is beautiful. And the Chairman commented on it as well, but each one of those points of light where we thought nothing existed, was not just a star, but a galaxy——

Dr. WEILER. Galaxy.

Mr. SMITH [continuing]. Consisting of an average of 200 billion stars. Just incredible the significance of that. The real question I wanted to ask you real briefly is, on the Next Generation Space Telescope, and part of the mission of that is to discover the Earth-like planets elsewhere. The funding was increased substantially, and we are appreciative of that, but the funding was still, I think, about $20 million short of the request. Do you see that adversely impacting the project or NASA's Origins Program?

Dr. WEILER. Yes. You are speaking about the House markup yesterday?

Mr. SMITH. Yes.

FUNDING FOR NASA SPACE TELESCOPES

Dr. WEILER. Yeah. The reason the funding is ramping-up is because the project is moving now into a hardware stage. Actually, we are about to go out with an RFP, a Request for Proposals, to industry. This won't be an in-house project. It will be done by the commercial world. We are—we are leading with that ramping-up budget to a launch in about 2000-end of 2008. And that is extremely critical because the way we are going to fund the Next Generation Space Telescope is by slowly decommissioning the Hubble Space Telescope over the same period.

And we had worked out a deal with the astronomical community, which they had accepted, that as Hubble would slowly end its life by 2010, we would build up NGST with that budget that would be freed up. And if we get into a potential chicken-and-egg situation, that Next Generation Telescope starts moving out, then the people that want to keep Hubble going will have a stronger argument—well, let us keep Hubble going. But if we keep Hubble going, we can't free up the money for NGST. So that $20 million would have an impact. It could be as much as, perhaps, a 6-month slip or more.

SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE

Mr. SMITH. Thank you. I hope we can, during the budget process, make up that shortfall. And I thank you for your answer. Dr. Chyba, you along with everybody else, so many questions, so little time. The first question I wanted to ask you goes really to study the search for extraterrestrial intelligence. And it seems to me that that search, that goal, has matured exponentially over the last 10 years. Ten years ago people were very skeptical. They had a hard time understanding why we should pursue that quest, why we should spend money on it, either in the private sector or public sector. But it seems to me in the last 10 years—and this is really what I want you to expand on if you will—that the search for extraterrestrial intelligence has become more credible for a couple of reasons.

The American people, I think, realize now that it is an achievable, practical goal that seizes their imagination. I think their credibility has been enhanced by individuals, such as yourself, who have become associated with SETI. Your scientific credentials are impeccable, as are the credentials of a number of other individuals associated with SETI. But how do you see it in the last 10 years, and where do you see us over the next 10 years, as far as SETI goes specifically and what we should try for and what we hope to accomplish?

Dr. CHYBA. Thank you. What I would say, Mr. Smith, is that understanding the prospects for other intelligent civilizations in the galaxy turns on a better understanding of life in the galaxy. And I think one of the reasons that the search for extraterrestrial intelligence has become much more credible is because we have learned so much more about the prospects for life elsewhere. As Dr. Weiler commented, it looks as though planets are common. We know now that life originated early in the history of the Earth. That suggests that perhaps life will arise wherever conditions are appropriate.

So as we learn more about the prospects for life elsewhere, and as it seems that—as it increasingly seems that the prospects are good, the question naturally follows of whether life on other worlds would lead to intelligence and whether that intelligence would lead to a technology that we could detect.

We don't assume an answer to that question. We don't know enough about the history of life on Earth yet to know whether intelligence is going to be rare or common. But one way of addressing the question is to search. If you don't search, in a sense you are already assuming an answer to this question. And we are not in a position to know the answer yet. So I think that is an important part of the answer.

Another part is that the technology, as you have said, has substantially increased. In fact, we are now at a position where SETI researchers are driving the development of the next generation of radio telescopes in this nation and also internationally. My colleague, Jill Tarter, at the SETI Institute, chairs the U.S. Consortium for the Square Kilometer Array because the most impressive prototype for that array is the Allen Telescope Array, which we are currently designing and will soon be constructing in northern California.

So I think that the technology is also beginning to match our aspirations. Over the next 10 years, the Allen Telescope Array should come online in 2005. It is on-time and on-budget currently. That will begin the search of the million nearest stars.

Looking farther ahead, you know, we convened over the past few years a working group that combined physicists, astronomers, and some of the most visionary technologists in Silicon Valley and elsewhere to ask what we should be doing. The Allen Telescope Array was the first recommendation. The second recommendation was an omni-directional sky survey which we will use to survey the entire sky all the time. And the third is to do some pilot projects, looking for potential signals in optical and infrared wavelengths. So we have a full plate, and so far, we are being very successful with pursuing those objectives.

Mr. SMITH. Thank you. And, Mr. Chairman, thank you for your indulgence. I hope there will be an opportunity to ask a couple of questions after everybody has finished.

Chairman ROHRABACHER. We may well be able to do that. Mr. Gordon.

Mr. SMITH. Thank you.

DIFFERENCES BETWEEN LIFE AND INTELLIGENT LIFE

Mr. GORDON. Dr. Weiler, would you define for me, please, in terms of extraterrestrial life, the difference between life and intelligent life?

Dr. WEILER. The difference between life and intelligent life?

Mr. GORDON. Yes, sir.

Dr. WEILER. I will look for any help I can get on this one.

Mr. GORDON. Well, what are we defining——

Dr. WEILER. How do we define intelligence is what you are asking?

Mr. GORDON. No. I——

Dr. WEILER. Oh.

Mr. GORDON. No. I think the difference between life and intelligent life is that—I mean, these are two different terms. Aren't they?

Dr. WEILER. Well——

Mr. GORDON. Well, okay.

Dr. WEILER. Let me try——

Mr. GORDON. Well, somebody else. Dr. Tyson, why don't you give it a try?

Dr. TYSON. I would be happy to try. I think we have this egocentrism about our species that we define ourselves to be intelligent and nothing——

Mr. GORDON. I have only got 5 minutes. Let me try——

Dr. TYSON. Yes. Sure. Sure. And let us——

Mr. GORDON. Be pretty quick.

Dr. TYSON. We define ourselves as intelligent and nothing else being so. And in that definition we imagine that we are the only species to contemplate our fate.

Mr. GORDON. So intelligent life is just us then.

Dr. TYSON. That is commonly—I don't think of it that way, but the broadest sense of that does——

Mr. GORDON. All right. Dr. Farmer, what would—-how would you define the difference between life and intelligent life?

Dr. FARMER. The question of intelligence——

Mr. GORDON. In terms of extraterrestrial.

Dr. FARMER. Yeah. I think the question of intelligence, you know, is more difficult to handle. But from a practical standpoint, I think it is a species that is able to modify its environment through technology and other means to substantially have control over their destiny. And I think that, you know, in terms of humankind, that is kind of what sets us apart.

Mr. GORDON. All right. And try to bring me—you know, a bacteria, microbe—that is life. Correct?

Dr. FARMER. Absolutely.

Mr. GORDON. Okay. Now, take me up to where it is intelligent life.

Dr. FARMER. Well, you know, and——

Mr. GORDON. And it is actually boys and girls, and then they have kids, and then they are able to hunt.

Dr. FARMER. I think, you know, I would trace it personally—and I know specialists in this area, but from my standpoint, I would view it in terms of the first technology developments that allowed humans to really gain an advantage in their environment.

Mr. GORDON. So is that levers and——

Dr. FARMER. Things like—yeah, the first Clovis points and things that they could use to hunt——

Mr. GORDON. Uh-huh.

Dr. FARMER [continuing]. To actually become very efficient, effective hunters——

Mr. GORDON. Okay. And what——

Dr. FARMER [continuing]. And some people believe that that led to the extinction of a lot of other species.

Mr. GORDON. I mean, I asked this question because there just seems to me an enormous difference between discovering extraterrestrial life and intelligent life. Do you want to—and would you want to add anything to our definition here and then I will go to the next question?

Dr. CHYBA. I would only add, Mr. Gordon, that with respect to the ancestors of humans, by about 30 million years ago, there were several species of dolphins on this planet who had brains that were larger related—in relation to their bodies than some of our tool-using ancestors——

Mr. GORDON. Uh-huh.

Dr. CHYBA [continuing]. Did. So it is not clear to me that we are the only intelligent species that have evolved or——

Mr. GORDON. So would you define—if we found a dolphin somewhere, would you consider that intelligent life——

Dr. CHYBA. I think that we would.

Mr. GORDON [continuing]. If you see one now?

Dr. CHYBA. As a practical matter, the only type of intelligence we are going to detect any time soon is technical intelligence, and humans are essentially unique in that respect.

Mr. GORDON. All right. Well, why don't we just start with Dr. Tyson. Again, I don't mean to be abrupt. We just have a short period of time here. This is hard, hard, I know, to—you want to put premises. But just give me your own gut feeling as to odds that there is extraterrestrial life and then that there is extraterrestrial intelligent life.

Dr. TYSON. Yeah.

Mr. GORDON. What odds? Just give me some odds.

Dr. TYSON. I would say it is near certainty that there is life elsewhere in the universe of any form.

Mr. GORDON. Okay.

Dr. TYSON. And I am somewhat more skeptical about the likelihood of intelligent life as we have defined it to be technologically capable, just given how rare that has exhibited itself in our own——

Mr. GORDON. Dr. Farmer, do you want to give a—give some odds here?

Dr. FARMER. Well, I would agree. I mean, I think that the kind of technical intelligence that we are talking about is probably rare.

Mr. GORDON. Well, just give me some odds. That is all I am really asking for right now.

Dr. FARMER. Well, I—you know, I think it is very hard to do. But I would—you know, these estimates that people have made are all over the map.

Mr. GORDON. Yeah. But I am just saying, you know, just——

Dr. FARMER. But within our own backyard, I would think that——

Mr. GORDON. I am just—well, you know——

Dr. FARMER. I would think on the order of hundreds of potential civilizations within our galaxy. I would feel comfortable with that.

Mr. GORDON. So do you think there is a 90 percent chance that there is life? At 80 percent? A 12——

Dr. FARMER. In our solar system, I have always said about 50/50 and that is—again, that is just—that is not——

Mr. GORDON. Okay.

Dr. FARMER [continuing]. Science. That is a personal opinion.

Mr. GORDON. Oh. No. No. That is what I am asking for. That is all I am asking for.

Dr. FARMER. And, you know, if you——

Mr. GORDON. And what about intelligent life? What kind of odds?

Dr. FARMER. In—beyond the earth and our own——

Mr. GORDON. Yeah.

Dr. FARMER [continuing]. Solar system, I would put at essentially probably nonexistent because I am——

Mr. GORDON. Okay. Dr. Weiler, how about you?

Dr. WEILER. I have learned never underestimate the ability of humans to make themselves special, number one. I believe the possibility of life, of any kind of life, including a bacterium in the solar system, is maybe 50/50; intelligent life, zero, other than the earth. In the universe, I think the probability of intelligent life is 1.0, 100 percent. To not believe in a universe with 1^{20}—to 10^{22} stars that intelligent life only sprung up on our little special place in the universe.

Mr. GORDON. Okay. How about you? Do you want to give some odds?

Dr. CHYBA. I think that it is almost certain that life exists elsewhere, although we don't know. And I think that it is quite possible that intelligent life exists elsewhere, but the only way to find out is to search.

Mr. GORDON. So what odds—how do you define quite—50? 40? 30? 20?

Dr. CHYBA. Mr. Gordon, I wish I knew. I just don't know.

Mr. GORDON. Yeah. But—well, I know you don't know, but what is your—if you—you know, what is your feeling? Nobody knows. Okay.

Dr. CHYBA. I would flip a coin.

Mr. GORDON. Okay. If I have just another moment, I—what—the—you know, the other question that sort of is my mind is that we are—the whole premise, sort of a common denominator, is an Earth-like condition. Are—again, is this ego or is there more basis to it than that? Are we limiting ourselves? And, again, you know, in our short period of time, Dr. Tyson, is it good to limit ourselves our flight conditions?

Dr. TYSON. No. It is not. And, in fact, that is what we used to think when we invoked the Goldilocks principle, that we are looking for an Earth-like planet at the right distance from the sun, but the whole study of biology and extraordinary environments has completely shattered that paradigm and now should allow us to look in many, many more places, including under the frozen surface of Europa, a moon of a planet that is well outside of this comfortable zone near the Sun. So——

Mr. GORDON. But now are you talking just in terms of temperature and gravity or are you going back to oxygen, you know, to things that—you know, water, the things we talked about earlier?

Dr. TYSON. Water primarily. And the——

Mr. GORDON. So you think there has to be water. If there is not water, then——

Dr. TYSON. It is compelling. The evidence is compelling. And given that, it has broadened our sense of where you might—what kind of conditions you might find liquid water. And not only that, given the extremophiles that we know exist at the bottom of the ocean, there are heated vents, that has completely broadened——

Mr. GORDON. But——

Dr. TYSON [continuing]. What it would mean to search for life.

THE ROLE OF WATER IN THE SEARCH FOR LIFE

Mr. GORDON. Dr. Farmer, do we need to limit ourselves to if there is not water, there can't be life?

Dr. FARMER. Well, the way I view it, we have one example that we know about and we should look to that for some education. And human intelligence really is deeply rooted. And a very special event that happened in our biosphere about 600 million years ago, and that was the build up of oxygen to a level to support oxidative metabolism, large multi-cellular animals with high metabolic rates. Eventually, that led to the kinds of things that we consider to be the things we are looking for. And, you know, maybe that is an absolute requirement. I really don't know. But it is hard for me to imagine the kinds of things that are associated with human biology developing in a non-oxygenated environment. So I would say that oxygen would be a key thing.

Mr. GORDON. Thank you.

Chairman ROHRABACHER. Next, will be Dr. Weldon.

Mr. WELDON. Dr. Farmer, I would just like to follow up on that line of questioning. I would assume water would be necessary as well. You mentioned oxidative environment. You know, I studied biochemistry, and we did not do a lot of experiments in the lab with—on solid surfaces. I realize there are other liquid environments. And I know Carl Sagan was fond of speculating about fluid environments that had other organic solvents. And I know there is some interest in one of the planets orbiting Saturn. But the example we have is a water environment. Correct? And didn't you essentially say that in your opening statement?

Dr. FARMER. Well, I mean, I think water is a fundamental requirement for all life, and I guess when I referred to oxygenated environments I was thinking more in terms of complex multi-cellular animals that have——

Mr. WELDON. That could produce intelligent life.

Dr. FARMER. Yeah. That led—on our planet have led to the technologies and things that we are looking for our there through SETI searches and so on. So——

Mr. WELDON. Right. Dr. Chyba—is that how you pronounce your name? Do I have that correct?

Dr. CHYBA. Yes.

SETI Institute Funding

Mr. WELDON. I understand the SETI Institute has been fairly successful at garnering private funds for much of the work they do. Is that correct?

Dr. CHYBA. Yes. That is correct. We—especially on the SETI proper side of the Institute. On the Life in the Universe side, we compete effectively for peer-reviewed grants that support about 25 principal investigators.

Mr. WELDON. And some of that is coming through Federal grants.

Dr. CHYBA. I am sorry. Yes. Yes, Dr. Weldon. That is——

Mr. WELDON. Or is that all Federal grants?

Dr. CHYBA. That is almost all Federal grants. We also do some private fund-raising on that side. About half of my personal research budget is private and half is from NASA grants.

Mr. WELDON. Is there anything that you have learned in fundraising for this type of research that you would like to share with us?

Dr. CHYBA. Well, I would say that the most important thing to us is our scientific credibility. It is essential that any potential donor, especially if it is a donor who has a reputation and a strong technical background, and our most important donors fall into that category—that they are convinced that our science is rock solid. So I think there is nothing more important to our Institute than our scientific credibility. And that is why we rely so heavily on external panels of experts to help guide the directions we should go in.

NASA Mars Missions

Mr. WELDON. Dr. Weiler, are there plans to redo any of the Mars missions? We had a couple of failures on some of the Mars probes. Is your office looking at repeating any of those missions in the near term?

Dr. WEILER. We just completed last year a total revamping of the entire Mars program. New Mars architecture—we spread the program out. We properly fund it at this time. Looked at the proper risk tolerance in the program. And we changed the way we are looking at Mars in terms of the whole theme of the Mars program is now "Follow the Water," building up ultimately to a sample return mission in the next decade.

We have a mission on the way to Mars right now—the Mars Odyssey, which should go into orbit in October, which has a thermal mapper which has the ability to look for hot spots, warmer spots on the surface which may be indicative of water or something under the surface, perhaps. We have two rovers, golf—they are the size of golf carts, that we are flying to Mars, landing in air bags, in 2003. They will be launched in 2003.

Mr. WELDON. The size of golf carts.

Dr. WEILER. The size of golf carts. Not the little rover you think of when——

Mr. WELDON. Right.

Dr. WEILER [continuing]. When you think of the Mars Pathfinder, but size. It is really a mobile geology lab almost. And instead of just going a few tens of meters, these things can go up to—

what, Jim? A thousand meters or a kilometer each. And we will be landing in two different parts of Mars. Again——

Mr. WELDON. Are you planning on a penetrator as part of the program? I know that was something you were looking at doing.

Dr. WEILER. Eventually. Do we have—I will—the—We just, in fact, selected some concepts for a smaller portion of the program called Scouts. This is where we actually reach out to the university community and ask them for ideas that we haven't thought of. And one of the ideas we selected was a penetrator to go down.

One of the big questions on Mars is, as Dr. Chyba said, you know, we are absolutely certain there was water on Mars billions of years ago. We are almost certain there may have been water on Mars recently. The real question is, how deep is it? Is it kilometers down or is it meters down? That could make a really big difference on how you would eventually plan a human mission to Mars.

Mr. WELDON. Yeah. Well, thank you, Mr. Chairman. I yield back.

Chairman ROHRABACHER. Ms. Lofgren.

Ms. LOFGREN. Thank you, Mr. Chairman. This is a treat to be able to listen to all of you. And I was—actually read some of the debate when SETI was defunded. It was before I was here in the House. And it was disappointing, actually, to read some of the comments that were made. And I think had I been here, I certainly would not have voted to defund the program. But having said that, it is—it occurs to me that the lack of Federal funding, in some ways, has benefited SETI. I mean, the creative things that you have done have been very cool. And I have been out to visit the Space Science Lab at Berkeley, and of course, NASA Ames is just a few minutes from my district. And the Allen Array is a very new and innovative way to proceed. And certainly the distributed computing program. I have got a confession to make. I have—I am—got the program on my computers in residences both in the East and West coast and also my office computer, both the East and West coast. And so that has also been innovative and interesting.

But having said that, I was interested in your comments that now might be a good time to partner in productive ways. And I sense that there has been a lack of interest, perhaps, on—from the NSF—or some resistance or problems in terms of SETI partnering or competing for grants. Can you address that? Is that not a correct assumption on my part?

SETI RESEARCHERS ABILITY TO COMPETE FOR FEDERAL FUNDS

Dr. CHYBA. Well, Ms. Lofgren, I would say that it is quite understandable that after the termination of funding in '94 that a variety of Federal agencies may have been left with the misimpression that that was a prohibition against any conversation regarding SETI or any peer-reviewed funding for SETI. And, in fact, it was the case that up until about a year ago, there was an explicit prohibition in the NSF's astronomical peer-review grants program, that they would not entertain SETI requests as they would other requests in radio astronomy.

That prohibition was recently removed by the Director, Rita Colwell. And I view that as just a kind of over-interpretation of Congress's intent in '94. My hope is that there would not be a similar perception in other agencies and that we will be able to compete on a level playing field in peer-reviewed areas and that we could pursue opportunities for partnerships.

Ms. LOFGREN. Well, I think, Mr. Chairman, that one of the values of having this hearing is for the Committee to make it known to Federal agencies that a bias against a good science application is not something that we would approve of and—nor are we seeking to earmark funds. But this ought—any application ought to be reviewed on its merits, and if it competes successfully, ought to be funded. And if it doesn't compete successfully, ought not to receive funding. And I don't think any member of this Committee would want a bias against good science, whether it is from SETI or for anyone.

One of the things that—I love the SETI program as a screensaver, but I have often thought what happens if all of a sudden, you know, I am the lucky one and I get to see a repeating pattern in a way that makes sense. If that happens—if you find something significant on your distributed computing program, how will you deal with that and how will you notify the world?

Dr. CHYBA. I should say that the SETI@Home project is out of the University of California, Berkeley.

Ms. LOFGREN. Right.

Dr. CHYBA. We did underwrite the Project SERENDIP, which did the initial data gathering. But, in fact, we are no longer directly involved with SETI@Home in any way. Nevertheless, the broader question remains. What happens if you detect something that seems to be a signal? The first thing I should say is that we have a set of requirements that any potential signal has to satisfy to be an apparent artificial phenomenon. There are no known narrowband transmissions produced——

Ms. LOFGREN. Right.

Dr. CHYBA [continuing]. By astrophysics. If we see one, it is almost certainly artificial. Or it could be some new type of physics that we simply have not seen in the astrophysical realm before. So we would not make an announcement that we had discovered extraterrestrial intelligence. We would make an announcement, and this would be done completely openly and publicly, that we had discovered a peculiar phenomenon that needed more observation. We would try hard to make that announcement only after there had been many levels of verification, so that we wouldn't give a false announcement which could be disastrous. But in this kind of high-profile science, I suspect that very quickly the public would hear if there was an anomalous signal that we were still trying to explain.

Ms. LOFGREN. I see that my time has expired. Mr. Chairman, thank you.

Chairman ROHRABACHER. Thank you. And Ms. Jackson Lee.

Ms. JACKSON LEE. Thank you very much, Mr. Chairman. I will not take all of my time. I appreciate the leadership of this Committee for having this hearing. Let me applaud the research that has been done. And I hope that as I characterize my remarks, my statement, which I know the Chairman has probably given a unanimous directive to admit our statements into the record—Mr. Chairman, I ask now that my opening statement might be admitted into the record.

[The prepared statement of Ms. Jackson Lee follows:]

PREPARED STATEMENT OF SHEILA JACKSON LEE

I would like to thank Chairman Rohrabacher and Ranking Member Gordon for providing this opportunity for the Subcommittee to examine the National Aeronautics and Space Administration's (NASA) efforts to search for signs of life elsewhere in the solar system as well as for Earth-like planets orbiting other stars. This hearing will also allow the Subcommittee to examine the research conducted by the privately funded SETI Institute.

The idea of life on other worlds beyond our earth has been one of the more popular discussions around the world. The question of whether life exists elsewhere in the universe or within our solar system has captivated scientists and lay people long before the development of our nation's space exploration efforts.

The focus of science has always been to delve into the unknown and find answers to questions. Answers to those questions have lead to a greater understanding of our world and the environment in which we live. People have dispelled many of the fears and myths regarding the unknown and relegated those beliefs to fairy tales and legends.

We are now at the start of the 21st Century, and with all of the technological innovations our society enjoys we do know that we have not reached the limits of understanding. The realm of our classroom has extended beyond the earth into the solar system and beyond.

Some may question the wisdom or reasons for seeking an answer to the question are there other forms of life in the universe? The search for an answer to this question can expand our understanding of life as we know it right here on Earth and increase our understanding of our solar system and Universe.

It has been and will continue to be the nature of people to ask questions that we do not know the answer to, and seek knowledge in the absence of evidence that an answer exists.

We do know from our tenure here on Earth that there is a wide variety of life coming in forms from microscopic to complicated systems such as those found within the Human body. The knowledge in recent decades have advanced our understanding of what conditions can sustain life to include the barren Arctic wastelands, caves where light does not penetrate, and locations of extreme heat.

Many life forms are not evident to the naked eye, but exist in their own ecosystem under conditions that people could not survive.

Our current goal in space exploration is to visit Mars. Toward that end our nation has funded a number of missions to that planet. An important note to remember in our consideration of the Mars surveyor missions that at some future date we hope to place people on the surface of that planet. Prior to that occurring it is important that the planet be carefully and thoroughly explored. Part of that exploration should include testing for signs of life that may have existed on the planet and life that might now still exist on Mars.

The belief that Mars is the most likely abode for life in the solar system has been one of the reasons it has been so desirable a target for robotic and eventually human exploration. In the 1970s, the first U.S. spacecraft to land on Mars-Viking—carried instruments specifically designed to test for the presence of living organisms. While those instruments gave readings that a few scientists believed were the result of biological activity, the majority of scientists believed that non-biological chemistry could account for the observed phenomena. Moreover, the radiation environment observed on the surface of Mars seemed to be quite hostile to the survival of any surface life.

Subsequent spacecraft-in particular the highly successful Mars Surveyor spacecraft currently in orbit around Mars-have rekindled interest in the possibility of Martian life (either extant or fossilized) due to the discovery of many Martian land features that appear to have been caused by the presence of large amounts of running water at some point in Mars' history, as well as features that suggest that there might be significant amounts of water-ice near the surface today. Since water is seen as important for the survival and development of life by many biologists, NASA has adopted a "follow the water" approach to Mars exploration.

Mars is not the only non-Earth candidate in the solar system to be considered a potential abode for life. Europa, a moon of the planet Jupiter, appears to have a liquid water ocean under a surface layer of thick ice. As a result, a number of astrobiologists believe that Europa could well harbor life in that ocean. Planning is underway at NASA for missions to better characterize conditions at Europa, with the eventual goal being a mission to penetrate the ice and explore conditions in the (presumed) water ocean underneath the moon's surface ice layer.

In addition, terrestrial biologists have been advancing new theories of the emergence of life on Earth. Earlier theories that posited the origin of life in nutrient-filled bodies of water have lost ground to theories that have been developed subsequent to the discovery of archaic forms of life existing under high-temperature, high-pressure conditions deep inside the Earth. As a result, astrobiologists are rethinking their approaches to the search for life beyond Earth in order not to overly constrain the conditions that are likely to signal the likelihood of life.

Another facet of the search for life elsewhere in the universe has been the search for Earth-like planets around other stars. It has only been in recent years that any solar systems with planets have been detected. However, those planets have been much more massive than our Earth and have orbited stars at distances or under conditions that would seem to render them incapable of supporting life. NASA is developing technologies that it believes will eventually allow the imaging of terrestrial-sized planets orbiting nearby stars—if such planets commonly exist beyond our solar system. If such images are obtained, scientists will then search for the presence of the ozone, water vapor, etc., which would be strongly suggestive of a planet with a biosphere.

Finally, one of the most intriguing searches underway is the search for extraterrestrial intelligence (SETI). This search is not directed at trying to find UFOs or alien visitors to Earth. Rather it is a systematic search of the nearby regions of the galaxy using radio telescopes in the hopes of intercepting radio communications emanating from advanced civilizations. The search does not assume that such a civilization will necessarily be attempting to make contact with other civilizations (such as Earth's). While that is one potential scenario, SETI search strategies have also assumed that a technologically advanced civilization will produce radio emissions that will travel outward into space from the home planet as a byproduct of that civilization—in the same way that TV and radio signals have been radiating outward from the Earth. NASA funded the SETI activity until 1993 when an amendment on the House floor eliminated all funding for the effort. Since that time, a non-profit SETI Institute was established that has been successful in attracting private donations to carry on the observing program, as well as to conduct a number of educational and related research activities.

I respect the science and appreciate the work that has been done by those private and public entities represented at our hearing today. However, I am not inclined to see the level of research regarding the prospects of intelligent life beyond our solar system as being of such high priority as to warrant a federal budget earmark. I am very supportive of the open peer review process of awarding federal grants to those who work to answer questions regarding life and intelligent life existing outside of our planet's environment.

I am looking forward to the testimony of today's witnesses. I thank them for sharing their expertise and insight, into this interesting aspect of space exploration, with this subcommittee. Thank you.

Chairman ROHRABACHER. So ordered.

Ms. JACKSON LEE. I applaud the concept and the research for its value. Certainly, I think that there is a lot of science to finding out different atmospheres in which life can survive. And I am more interested in that concept of survival. Let me, however, say that I am not a proponent. I might not have voted to eliminate funding in '93, but I am not a proponent of earmarking or focusing on funding at this point. I am interested in the science to the extent that the applications can teach us things here on earth and that it is a reputable science that in a grant process certainly should have the opportunity to compete.

So my brief question is, how does the science that we learn and the applications that we may develop help us here on Earth? When I speak of the Space Shuttle and the Space Station, I speak of the kind of research that impacts HIV/AIDS and diabetes and stroke and heart disease. I think when we sent John Glenn to—in the last—or in a couple of years ago, into space again, it was on the question of aging. So, Dr. Chyba, is it, I would appreciate your response to that. And I thank the Chairman——

Dr. CHYBA. Thank you. And——

Ms. JACKSON LEE [continuing]. And the Ranking Member for his patience.

Dr. CHYBA. Thank you. And I agree with what you said about earmarking. As I said in my testimony, we are not requesting any earmarking. I think that the kind of benefits to humanity are both concrete and less concrete. The more we understand about our place in the universe, the more we understand ourselves, and that is simply important, in and of itself.

And another benefit which I think cannot be underestimated is the ability of this kind of research to inspire young people and students. The National Science Foundation currently funds the SETI Institute to develop a high school—an integrated high school science curriculum. And we use the interest of young people in extraterrestrial life and potentially extraterrestrial intelligence to teach them physics and chemistry and biology in an integrated way that I think captures their imagination.

More practically, the sort of electronics and computer technology that we are driving with things such as the Allen Telescope Array and Project Phoenix, will eventually have ramifications for practical applications on earth. For example, one spin-off of the technology being developed, has to do with—you see, with the Allen Telescope Array, we will, in effect, be synthesizing images. That has potential applications for medical imaging here on earth. And, in fact, there is a spin-off being pursued that has to do with imaging for cancer research.

Ms. JACKSON LEE. Mr. Chairman, let me—and to the Ranking Member, again, thank you, and say that I think that if this Committee moves forward in any kind of consensus on this research, it will have to be the practical applicability of what is occurring and for the public to understand that impact. And I would argue that we need to be cautious and sensitive, but respectful of the research. And I look forward to us looking at this issue further. I yield back the balance of my time.

Chairman ROHRABACHER. Mr. Wu.

Mr. WU. Thank you, Mr. Chairman. I have no questions at this time. Life in the universe is beyond me. I am just trying to find life in Washington, D.C. somewhere.

Chairman ROHRABACHER. Yes. We have been all involved with that search for a long time, intelligent life especially. Let me just say this that—well, I have some time for some questions. I haven't had my questions in yet.

Dr. Chyba, I want to again call attention to the fact that when we tried to balance the budget, and that was in a very—we believe that was a very important accomplishment. We had to make some tough decisions. And I think that your testimony here today underscores that there are many things that are of value in our society that don't necessarily have to be funded directly from the Federal budget.

I remember when there were cuts in certain ballet programs in certain cities. The cities got together with the people and raised money locally to support their local ballet, which I thought—and orchestra programs. And I thought that was demonstrative of the fact that sometimes we believe that all—everything of value has to be or have some part of the Federal budget and even earmarked part of the Federal budget. So we wish you success—continued success in private funding, as well as some of the other programs which are subsidizing you from the Federal level, as well, that can be traced back to the Federal budget.

That means we have 15 minutes. Is that right? So it is the intent of the Chairman to finish asking his questions and then to give Lamar Smith——

Mr. SMITH. Thank you, sir.

UNIDENTIFIED FLYING OBJECTS

Chairman ROHRABACHER [continuing]. A couple more minutes and Mr. Gordon a couple more minutes and then to break and to hold the hearing in conclusion. Okay. I am going to ask the question nobody else has the courage to ask. What about it? What about these objects flying around? And when I was a—I was a young reporter, I remember I covered a story with two policemen in Los Angeles. And these guys took their careers in their hands, because they knew anybody who would make a report like this would likely to be hurt in their career—not helped, but hurt. And they said they saw a metal object floating down the street in Los Angeles about—it must have been about three o'clock, four o'clock in the morning and they chased this thing. These were two reputable people. They have no doubt about it that they were fine men, not lying, because if they did, they were lying in a way that would really hurt their potential careers. Is it potential that we have got not only life out there, but some of those intelligent life involved with visiting this planet?

Dr. TYSON. Are you going down the line? Okay. I will be happy to start. First of all, in science, we have learned, and there are extraordinary scientific examples to back this up—we have learned in science that among all forms of evidence you could bring forth, the least reliable is eyewitness testimony. And apologies to attorneys in the audience, that is just the way it is. And it doesn't matter what it is you are talking about. It could be something that doesn't have enormous implications for having been visited by aliens. It could be spectral line strengths in a red giant atmosphere. If you are just going to say I saw it, no one will believe you unless you can bring forth higher quality evidence. And so that is my first comment.

My second comment is, I spend my life working in a museum where artifacts matter. That is what gets put on display.

Chairman ROHRABACHER. Okay. Have you ever seen any physical evidence? I mean, I have seen lots of pictures. And I mean, we have all seen these photos. Have you seen any physical evidence that would indicate to you that——

Dr. TYSON. The answer is, no, and it wasn't for want of trying. I visited, for example——

Chairman ROHRABACHER. All right.

Dr. TYSON [continuing]. The UFO Museum in Roswell to see what a museum of such artifacts would be. And it was filled with newspaper accounts of people's eyewitness testimonies——

Chairman ROHRABACHER. Right.

Dr. TYSON [continuing]. Mounted and not actual artifacts. And so I was disappointed, actually. But it falls far short——

Chairman ROHRABACHER. Okay.

Dr. TYSON [continuing]. Of what you would consider——

Chairman ROHRABACHER. You would like to believe it, but you don't.

Dr. TYSON. Yeah. It is——

Chairman ROHRABACHER. Okay.

Dr. TYSON [continuing]. Non-compelling.

Chairman ROHRABACHER. Okay. Dr. Farmer.

Dr. FARMER. Well, I think this question of alien visitation has always managed to remain on the sort of outside of the purview of science. We have never really been able to seem to get a grip on anything that is contestable.

Chairman ROHRABACHER. Just remember, if we are sending probes out there, we are the alien visitors out there and——

Dr. FARMER. Well, that is right. Yeah.

Chairman ROHRABACHER [continuing]. It wouldn't——

Dr. FARMER. And——

Chairman ROHRABACHER. Other people might want to do the same if they existed out there.

Dr. FARMER. But I—you know, I guess, I—on a personal level, I can't say that I am disinterested. I have to admit that the show "Roswell" kind of captured my imagination last year. The great young actors—I became very concerned about the well-being of those aliens in the Earth environment. I was, you know, not so concerned about humans. Regarding human abduction, I would just love to sign up, but, you know, I raise my hand nobody picks me up. You know, I would love to go. But——

Chairman ROHRABACHER. All right. So—but you don't——

Dr. FARMER [continuing]. That is all I have to say.

Chairman ROHRABACHER. You don't believe——

Dr. FARMER. I haven't seen anything that would——

Chairman ROHRABACHER. You have seen no compelling evidence of——

Dr. FARMER. No.

Chairman ROHRABACHER. Dr. Weiler.

Dr. WEILER. Although I think life—I used to be a ground-based astronomer before I worked for NASA and I have spent thousands of hours of looking at the sky. And I would call myself an experienced observer. I have seen lots of moving objects in the sky, but I have always been able to point them out as satellites or other things. So personally, I haven't had any direct experience.

Although I believe, in my heart, that there is 100 percent chance that there is alien life out there, intelligent life, I am also a physicist and recognize the physics I understand, and we understand at this table, with the best technology we have, it would take hundreds, if not thousands of years, to make the trip to the nearest star. Unless there is some physics out there we don't understand yet, and I also believe that is true.

Chairman ROHRABACHER. Right.

Dr. WEILER. The idea of some technological society visiting us frequently just is—it is hard to contemplate.

Chairman ROHRABACHER. All right. Dr. Chyba.

Dr. CHYBA. Mr. Chairman, I believe that in your opening remarks you mentioned the film, "The Day the Earth Stood Still," a classic movie. And it is that film that has always made me puzzled by some other reports. It seems to me that if an extraterrestrial civilization were going to visit, they would quite possibly do the obvious thing, land right on the Ellipse near the White House. Why is it that so often they seem to buzz remote places rather than come down over a city? But nevertheless, I would have to say that——

Chairman ROHRABACHER. And make contact with some of the most uninteresting people.

Dr. CHYBA. I have to say that fundamental to the scientific attitude is to have an open mind. So I think that we should keep an open mind. But that open mind has to be coupled with skepticism. That has to be coupled with skepticism in our own research and it has to be coupled with skepticism toward eyewitness testimony. But we need to keep an open mind.

Mr. Chairman, just returning to your previous comments, right before you asked the question, again, we are not asking for an earmark. All we would like to see is a level playing field where the SETI science is treated in the same way, peer-reviewed way, as other science.

Chairman ROHRABACHER. Thank you very much. Just for the record, this Chairman does not dismiss all of these reports. I mean, I—when I was a young man, those two policemen were very convincing, and they saw something. I don't know what they saw. They were trained observers, and we have seen reports from people who are very credible. Now, I don't know what it is, and there may be black—and I know that there are black programs in the United States Government. I worked in the White House for a while where there was incredible things going on right in the next office, and I didn't know about it. And let me just say that—and that—I think that is true of every White House. But different things go on next door in different White Houses. And we won't go into any details.

But let me just say, I think that a healthy skepticism is important, but I think an open mind toward these things is also important.

Dr. TYSON. Your mind shouldn't be so open that your brains fall out. So just—open minds are important, but——

Chairman ROHRABACHER. That is what I say. I am open-minded, but I am not the Grand Canyon.

Dr. TYSON. Right.

Chairman ROHRABACHER. So, Mr. Smith, we have just a few minutes. So——

Mr. SMITH. Okay. I will be brief.

Chairman ROHRABACHER. Yes.

SETI PEER REVIEWED FUNDING

Mr. SMITH. Mr. Chairman, thank you again for having this hearing. Ms. Lofgren, a while ago, mentioned an important subject, and that is the SETI screensaver, which I have on my computer in my office, as well. But what I wanted to point out is that there are two-and-a-half million people around the world that use that screensaver, so there is a lot of interest in the subject.

I also think it is significant, Mr. Chairman, that there was bipartisan support expressed today for the idea of allowing various organizations, including SETI, to compete for funds in peer-review areas. And I think that was significant to hear a number of individuals comment on that.

Dr. Chyba, you mentioned the cost of the Allen Telescope Array, I think, it being around $30 million. And I just want to point out that I think the cost is literally miniscule compared to the significance of the discovery of extraterrestrial intelligence, when and if that time comes.

Mr. Chairman, finally—and I guess this will lead to a question, but I just wanted to see if our witnesses today agree with me that it is likely that in the next 10 years we will discover microbes within our own solar system and discover Earth-like planets likely to harbor life outside our solar system. If you agree with that, I would be interested in knowing that. But my question is, how do we speed that process up? I think I know the answer, but I would like to hear our panelists address that, if they would. Dr. Chyba, let us start with you. Oh. And if you—the Chairman tells me you have 2 minutes at most, so just a real quick response from a couple of individuals would be appreciated.

Dr. CHYBA. Mr. Smith, I will be very brief. Therefore, I would say that one of the most exciting places in the solar system is Europa, because there is almost certainly an ocean of water underneath the ice of that world. I think it is very important for us to return to Europa with a dedicated mission. Currently, the earliest that mission would be launched is in 2008. It is a 3-year flight to get there. So we won't find out the answer to your question for Europa within this decade.

Mr. SMITH. Anyone else? Dr. Tyson.

Dr. TYSON. Yeah. I would want to quickly clarify for the record that the SETI@Home screensaver has now reached its 3 millionth person. And——

Mr. SMITH. Thank you.

Dr. TYSON [continuing]. That was originally funded by the Planetary Society, a 100,000-member organization, on whose board I serve. So the broad-based support for SETI goes beyond——

Mr. SMITH. Is growing. Okay.

Dr. TYSON [continuing]. The SETI Institute itself.

Mr. SMITH. Thank you, Mr. Chairman, very much for the time that——

Chairman ROHRABACHER. Thank you, Mr. Smith, for recommending that we hold this hearing. And it has been delightful and entertaining, but also provocative. And I would like to thank our witnesses for testifying. Thank you all very, very much. And please be advised that the Subcommittee members may request additional information for the record. And I would ask other members who are going to submit written questions to do so within 1 week of the date of this hearing. That concludes the hearing. We are now adjourned.

[Whereupon, at 12 p.m., the Subcommittee was adjourned.]

Appendix 1:

MATERIAL FOR THE RECORD

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Edward Weiler to questions submitted by the Honorable Dana Rohrabacher, Chairman of the Subcommittee

QUESTION 1: Is NASA ensuring that research proposals for the scientific search for extraterrestrial intelligence (SETI) are eligible and considered fairly under peer review within NASA's Announcements of Opportunity, NASA Research Announcements, Cooperative Agreement Announcements, and Broad Area announcements for Space Science, Astrobiology, and other relevant disciplines?

Dr. Weiler's Reply: NASA is no longer prohibited by an congressional language from considering or funding SETI research, so SETI is currently eligible and considered fairly under peer review for NASA opportunities. In fact, there are a number of current grants issued to the SETI Institute by NASA. It should be noted, however, that NASA does not generally fund ground-based radio astronomy—only in cases where long-standing NSF policy precludes scientists from government agencies, federally funded research and development centers, national laboratories, etc., from competing does NASA normally fund ground-based radio astronomy.

Responses by Dr. Edward Weiler to questions submitted by the Honorable Bart Gordon, Ranking Member of the Subcommittee

QUESTION 1: The moon Europa was identified as a likely candidate to have liquid water ocean and thus as a potential site for the existence of extraterrestrial life.

Does NASA consider Europa to be a high-priority destination for its planetary program?

Dr. Weiler's Reply: Yes. Recent developments in our understanding of the solar system have strengthened the case for the Europa Orbiter (EO) mission as a compelling and essential part of NASA's planetary program. The EO mission has received strong endorsements by the Office of Space Science's external advisory groups and the scientific justification for EO remains strong. The Galileo mission results have strengthened the case for a water ocean but have led to no consensus about ice thickness or the conditions beneath the thin, outermost brittle layer of very cold ice. A well-instrumented EO mission will help scientists to determine whether there is an ocean on Europa and to identify some aspects of the nature of this subsurface environment that might support life.

QUESTION 2: The EO mission launch date has now slipped to 2008. What are the reasons for the slippage, and what is the likelihood of further schedule slippage?

Serious technical and programmatic problems surfaced in the Europa Orbiter mission in the winter, 2000. Chief among these were the following:

a. *Because of increased total mission mass, the selection of a launch vehicle was uncertain, creating the possibility that the previously chosen vehicle would not meet NASA qualification requirements;*
b. *The radioisotope power source development schedule had slipped, and its cost had increased; and*
c. *The estimated budget profile for fiscal years FY 2001- 2006 far exceeded the level that the Office of Space Science could support.*

Dr. Weiler's Reply: As a result of these problems, a 'grass roots' analysis was undertaken of the entire mission, factoring in the technical problems to date and requiring adequate programmatic and technical margins. That analysis resulted in the new launch date of 2008 and the funding requirements presented in the President's FY 02 budget. Much of the core avionics that enables spacecraft operation in Europa's radiation environment is under contract and on track for delivery well in advance of the needed date. Issues of launch vehicle qualification are well understood and NASA's Office of Space Flight is confident that the Delta 4 Heavy launch vehicle will be available. Finally, there has been a careful assessment of radioisotope power source options, and the required technical developments are understood and can be accomplished in time to support the launch. This assumes that there are no significant changes to the FY 2002 President's Budget and its run-out.

The outcome of the FY 2002 appropriations process may have significant implications for the Europa mission schedule. The current version of the Senate VA/HUD/IA Appropriations bill includes funding for a mission to Pluto that was not requested in the President's Budget. One potential implication is the fact that there are currently only two suitable power sources—Radioisotope Thermoelectric Generators (RTGs)—in existence, both of which are required for the Europa Orbiter mission. A Pluto mission would also need at least one of these RTGs. Thus a Pluto mission, if it were to go forward, could effectively cancel the Europa Orbiter mission.

Answers to Post-Hearing Questions

Responses by Dr. Chris Chyba to questions submitted by Honorable Bart Gordon, Ranking Member of the Subcommittee

"In your oral testimony you indicated that the current SETI initiative was providing "spin-off benefits to the American public. Please provide specific examples of the spin-off benefits that you believe have or will come from the SETI initiative."

Dr. Chyba's Reply: SETI research has had concrete spin-offs both for biomedical technology (as I mentioned in my testimony, for the detection of breast cancer) and for more conventional astronomy. It has also provided what I would call "educational spin-offs."

The idea behind the technology spin-offs is that signal-detection techniques developed to perform the data-intensive SETI searches provide sophisticated but general methods for detecting extremely weak signals in the midst of background noise. This means that the SETI detection algorithms could potentially be applied to a wide variety of non-SETI applications that require a similar "search for a needle in a haystack".

Perhaps the most concrete example concerns a very important biomedical problem, the detection of breast cancer in its early stages. Thirty-two million screening mammograms are performed in the United States annually. But since 95% of mammograms are normal, if mammogram screening could be automated with a very high degree of reliability, the cost of breast cancer screening could be significantly reduced and, just as importantly, doctors would have more time for examining the small fraction of mammograms that show something suspicious. Computer-aided diagnosis could become routine as digital technologies come into use for mammogram images. Mathematically, the detection of weak signals coming from distant stars is very similar to the detection of the micro-calcifications that signal the possibility of cancer, but which can be lost or hidden in all the background structure in the mammogram X-rays.

This research has been done by a team of researchers including two SETI Institute scientists, Dr. Kent Cullers (Director of SETI Research and Development) and Dr. Richard Stauduhar (a SETI signal detection expert). These researchers have worked with Drs. Laurence Clarke, Stanley R. Deans, and John Heine of the Moffitt Cancer Center at the University of South Florida. The techniques have been published in peer-reviewed journals, including the *IEEE Transactions on Medical Imaging* and the *Journal of the Optical Society of America.* These papers formed the basis for a patent application, "Normal and abnormal tissue identification system and method for medical images such as digital mammograms." We have just been told informally by the University of South Florida that the patent has been approved.

In addition to medical technology applications, SETI research has had significant spin-offs in areas of astronomy. One example lies in the detection of planets around other stars. The "matched filter" detection algorithms developed for SETI are used in the *Kepler* mission, a spacecraft mission under consideration by NASA to detect extrasolar planets by searching for a slight dimming in the light from the star as a planet moves across its face. Once again, the SETI techniques are helping to pull a faint needle of a signal out of a haystack.

A second example of a spin-off lies with the impact that the design and construction of the Allen Telescope Array (ATA) will have on future radio telescopes. As I described in my written testimony, until now it was only practical to construct the collecting area for a major radio telescope as a single enormous dish (as at Arecibo, Puerto Rico), or as several large dishes (the Very Large Array in New Mexico has 27 dishes) whose output is combined. But the ATA will be constructed using over three hundred fifty mass-produced dishes—at about 20% of the price of a conventional radio telescope of the same collecting area. SETI telescope technology research has resulted in a cutting-edge design that will alter the way that future radio telescope facilities are built.

The Square Kilometer Array (SKA) is an international ground-based radio telescope that will have a million square meters of collecting area, making it one hundred times more sensitive than the most sensitive existing radio telescopes. The National Academy of Science's last decadal review endorsed a technology development program for the SKA, for the "unprecedented images" and "great discovery potential" that it will allow. The SKA is a major part of the future of radio astronomy, and the ATA is pioneering techniques that could be used to build the SKA. In effect, the ATA is the leading prototype for the SKA—so that the SKA design might well prove to be another SETI spin-off.

One final, but very important, spin-off from our SETI work is what I would call the "educational spin-off". The Institute has substantial education and public outreach components, both in the form of hundreds of talks given by Institute scientists to audiences of all ages, and more formally in terms of curriculum development. Our Voyages Through Time project, funded by the National Science Foundation, is a one-year high school integrated science curriculum focussing on evolution as an overarching theme: from the Big Bang through biology to the evolution of technology. Voyages Through Time will begin national field testing in September. Speaking from my personal experience as a teacher and as a public lecturer, a powerful way to inspire young people, and to attract and hold the interest of adults, is to teach science in the context of exciting questions such as the scientific search for life elsewhere in the universe. Addressing this problem scientifically requires elements of all the sciences, and the "hook" of searching for life helps make teaching basic or advanced concepts in these areas more appealing to students of all ages.

I hope that these comments have fully answered Mr. Gordon's question, and I would like to take this opportunity to thank the Chairman and all the members of the Subcommittee for giving me an opportunity to testify.

Dr. Chyba requested that written testimony from Dr. Jill Tarter of the SETI Institute be included as part of his testimony.

[The testimony of Dr. Jill Tarter follows.]

PREPARED STATEMENT OF JILL TARTER

SETI—The Search For Inhabited Worlds

By Jill Tarter, Bernard M. Oliver Chair for SETI, SETI Institute, Mountain View, CA

Humanity has been asking itself whether or not it shares the cosmos with other sentient beings since the dawn of civilization. Prior to the second half of the twentieth century, this question could only be answered in terms of formal belief systems in use at any time and place. Literature records the complex and fascinating deliberations of many philosophers, religious leaders, and natural scientists on this topic. The development of more sophisticated astronomical instruments, with which we can remotely observe the universe we inhabit, at many different frequencies, has provided the opportunity for humans to attempt to answer this age-old question experimentally. SET[(the search for extraterrestrial intelligence) became a legitimate arena for scientific exploration slightly over four decades ago with the publication of the first paper in a scientific journal by Cocconi and Morrison in 1959 and Frank Drake's 1960 Project Ozma, the first search for radio signals from two nearby Sun-like stars. Since that time a hundred different search programs have been reported in the scientific literature, and undoubtedly the negative results of many others have gone unreported. The reported searches span the electromagnetic spectrum from very long wavelength radio waves to the ultra short wavelength Gamma-rays, however the bulk of the searches have utilized centimeter wavelength radio astronomy techniques. This is where nature presents us with a quiet window on the universe, with minimal natural background radiation.

In order to distinguish technology from astrophysics, researchers look for signals that are more compressed in either frequency (narrowband) or time (pulses) than natural emission processes can generate. Due to scattering in the interstellar medium, and the intrinsic brightness of a star at visible wavelengths, the most plausible candidate signals are narrowband (continuous waves or long duration pulses) in the radio, and very short, wideband pulses in the optical/infrared. Narrowband detectors have been available at radio frequencies for decades. The recent development of affordable, fast photon detectors at optical wavelengths, with the capability to see very short pulses, has made optical SETI (OSETI) begin to look attractive as a search strategy for nearby stellar targets. Beyond about 1000 light years, interstellar dust begins to scatter and absorb optical photons. Longer wavelength IR and radio photons propagate through the interstellar medium without being appreciably absorbed.

Having selected a frequency, and signal type, it is still necessary to choose a strategy for conducting a search. There are two basic strategies; a scan of the entire sky or a targeted approach that selects specific directions in which to point a telescope, directions with an *a priori* higher probability of containing a signal. Stars like our own Sun are the targets of choice. The only technological life that we know evolved around just such a star. This could be a poor guess, or the correct star may be so very distant that it does not yet appear in our catalogs of known stars. Even though it always has poorer sensitivity (less time can be spent observing any particular direction or frequency), a sky survey might succeed in finding an extremely powerful transmitter at great distance, where a targeted search of nearby stars might fail. The ideal search program encompasses both strategies. Figure 1 is an illustration of the sort of decision tree that ultimately leads to a particular SETI search project. Note that the tree starts with decisions about whether to look for artifacts, or exotic particles, or signals. The case for signals was cogently argued in the seminal Cocconi and Morrison paper, and again in the early 70's during an extraordinary NASA/ASEE engineering design summer study that culminated in the publication of the *Cyclops Report,* and again most recently during a series of workshops sponsored by the SETI Institute leading to a roadmap for SETI research for the next two decades titled *SETI 2020.* The shaded boxes reflect the specific choices made by the Cyclops design team. The digital revolution and increasing computational capacity in modern technology now enable a change in the last branching to permit a more efficient targeted radio search of many different target stars simultaneously. This has led to the recent decision to build a dedicated array of radio telescopes for doing SETI research (see below), an array that can in fact do traditional radio astronomy simultaneously with the search.

Since the 70's the astronomy and astrophysics community has conducted a decadal review and prioritization of the scientific programs that it would like to see pursued over the subsequent ten-year period. In each of the four such studies conducted under the auspices of the National Academy of Sciences, SETI has received endorsement as a high-risk, high-potential-payoff, program of scientific exploration on which modest funds should be expended. NASA heeded this advice and began a small SETI project in the mid 1970's. Research and development efforts culminated in a new start for NASA's High Resolution Microwave Survey (HRMS) in 1989. A ten-year observational program comprising both a targeted search and a sky survey component was launched on October 12, 1992, the quincentennial anniversary of another significant exploratory venture. One year later, concerns over federal deficits led to the cancellation of the HRMS project.

Since that time, all SETI research has been privately funded by philanthropic donations from individuals of great and small financial means. The SETI Institute, founded in 1984 to enable a more cost effective mechanism for conducting SETI research, has been a leader in this private continuation of the federally funded efforts. From its incorporation, the SETI Institute has encouraged and supported a growing cadre of research scientists studying the nature, distribution, and prevalence of life in the universe. They have routinely embraced and studied all forms of life, from the simplest to that which can be detected by virtue of its purposeful use of technology. For nearly two decades, the SETI Institute has been pursuing what is today known as the discipline of astrobiology, in its full and logically complete scope.

Today, there are a dozen observational SETI programs being conducted globally. Some of these projects are sky surveys, some are targeted searches, some are at radio frequencies, and some are searches for optical pulses, some have direct command of the observing instruments, and some go along for the ride in a piggy-back fashion. Most of the searches are in the United States, but a growing number are based in other countries. These searches are not equally sensitive. The SETI Institute's Project Phoenix is the most comprehensive of these search programs. By significantly improving the instrumentation originally developed for the NASA HRMS project, the SETI Institute has been able to create a real-time search system that can detect signals comparable in strength to terrestrial radars out to a distance of 155 light years from Earth. The Phoenix project is searching through the microwave spectrum from 1200 to 3000 MHz, pointing at the nearest 1000 Sun-like stars using the world's largest radio telescope at Arecibo Observatory (in Puerto Rico) and the Lovell Telescope at Jodrell Bank Observatory (in the UK) simultaneously. The use of two widely separated telescopes allows Project Phoenix to discriminate between possible extraterrestrial signals and those that are produced by our own technologies. The search is highly automated and efficiently scheduled. Whenever a candidate signal is detected at both observatories, with the proper characteristics, the observing schedule is interrupted and additional observations are automatically made to validate the signal. Most candidate signals are rapidly identified as some form of human-caused interference. On the rare occasions when candidates continue to look like possible extraterrestrial signals, human intervention is required. To date, no signal has passed the stringent requirements set to establish its extraterrestrial origin, except those from the (now interstellar) Pioneer 10 spacecraft which serve as a daily check on the system performance. The Phoenix project has looked at approximately half its target list, and will continue operating through 2005.

The four decades of active research, the 100 projects reported in the literature, the growing international participation, and the enormous success of the *SETI*@home distributed computing experiment (with more than 3 million downloaded screen-savers to date) may give the impression that SETI searching has been exhaustive. Nothing could be farther from the truth. The cosmic haystack, within which a signal might be buried, is vast and nine-dimensional. Project Phoenix, which carries out the most comprehensive investigation of our galactic backyard, is allocated only 500 hours a year of telescope time—a very large allocation on a heavily subscribed scientific instrument, but far from the desirable 24×7. The numerous search programs now on telescopes should be taken as indicators of the strong international public interest in SETI as a scientific program, and the inventiveness and tenacity of SETI researchers. The search has hardly begun.

In 1997–1999, the SETI Institute sponsored a series of workshops to chart a roadmap for the next twenty years of SETI research. The workshop participants were astronomers, physicists, and engineers from around the world, in addition to a number of technologists. From these workshops emerged three concepts; the current interest in optical SETI, a long-term plan to build a radio telescope that can look for transient signals in all directions on the sky at one time (once Moore's Law renders the computational costs manageable), and a blueprint for a dedicated SETI telescope implemented inexpensively by arraying a large number of small antennas together. This last concept was called the One Hectare Telescope because it would have a total collecting area of 10,000 square meters, or one hectare. Today the SET[Institute is partnered with the Radio Astronomy Laboratory of the University of California Berkeley and is hard at work on the technology development for this revolutionary new telescope that will be able to do a targeted SETI search in parallel with, rather than in competition with, traditional radio astronomy. Named in honor of Paul G. Allen, the Allen Telescope Array should be operational by 2005. It will be a world-class instrument with unprecedented instantaneous frequency coverage, and the ability to speed up SETI searches by forming synthesized beams to observe many target stars simultaneously. The cost is expected to be between 10% and 20% of a traditional, fully steerable, antenna or array of comparable collecting area. Using consumer market technologies, or derivatives therefrom, is the key to lowering the cost. If the Allen Telescope Array lives up to its promise, it will fundamentally alter the way large antennas are constructed for radio astronomy, and for deep space communications. It will speed up SETI searches by two orders of magnitude, provide a premier instrument for radio astronomical research, and pave the way for even bigger systems in the future. Figure 2. depicts the search coverage of some of the multiple dimensions of the cosmic haystack. The horizontal axes are the fraction of the sky that has been covered, and the frequency coverage within the microwave spectrum. The vertical axis is the sensitivity of a search, and is a measure of how far away a given signal could be detected. The ATA will greatly improve the frequency coverage, and search perhaps a million nearby stars out to a distance of 1000 light years, but much of the sky will still remain unexplored. If searches with the ATA and improved OSETI systems fail to provide a detection in the coming decade, better instruments will need to be built.

OSETI searches will need to be moved from their current 1 meter class telescopes onto 10 meter instruments. Because detection of rapid pulses can be accomplished without making a good image of the target star/transmitting planet, it may be possible to inexpensively share the large, light-collecting arrays being planned to detect Cherenkov radiation from the highest energy cosmic rays (VERITAS is one example). The single optical flashes now discarded in the search for large, extended airshowers might well include OSETI signals from a distant technology. At radio frequencies, another type of sharing may also be feasible. The international radio astronomy community has joined forces to design a new radio telescope that will have 1 million square meters in collecting area, the Square Kilometer Array (SKA). This is a hundred times larger than the Allen Telescope Array, or any existing radio astronomy array, and means that fainter sources can be seen at distances ten times further away. It will be used to understand the structure of the universe before stars and galaxies formed. Plans call for the array to be able to synthesize 100 different beams on the sky at any one time. Adding another 10 or 20 dedicated SETI beams to the SKA (for small incremental costs) will permit, for the first time, SETI searches for signals no more powerful than current terrestrial TV broadcasts. The challenge is to find a way to build the SKA as an affordable project that is international from birth. The small parabolic dishes of the Allen Telescope Array are the favored approach of the U.S. SKA Consortium of ten research and academic institutions, but this approach will demand a daunting computational capacity for radio imaging. Canada, China, Australia, The Netherlands, and India have other concepts of how best to meet the science goals of the SKA for the lowest costs. A decision on the preferred design and site for this facility is scheduled for 2005. SKA technology development studies on the Allen Telescope Array will provide a very credible price/performance demonstration in time to influence that design choice. It is worth noting that a million square meters of collecting area on the ground, in an extended array configuration, would provide more than enough sensitivity to support the high speed data rates needed for downlinking movies rather than still images, as well as three-dimensional tracking and navigation for the large number of smaller spacecraft that NASA would like to launch in the coming decades, while requiring only low or medium gain on-board antennas.

For these reasons, the NAS *Astronomy and Astrophysics for the New Millennium* decadal review recommended:

> *"The Search for Extraterrestrial Intelligence*
>
> *Are we alone in the universe? Finding evidence for intelligence elsewhere would have a profound effect upon humanity.. . .This committee, like previous survey committees, believes that the speculative nature of SETI research demands continued development of innovative technology and approaches, which need not be restricted to radio wavelengths. The privately funded One-Hectare Telescope (1 hT), which will be the first radio telescope built specifically for SETI research, is a good example of such an innovative approach, and it will pioneer new radio techniques that could be used in the SKA."*

And:

"Square Kilometer Array

. . .SKA's sensitivity will be a factor of 100 greater than that of existing centimeter-wave facilities. The increase in sensitivity has great discovery potential, and SKA will revolutionize the study of objects and phenomena that are currently undetectable at centimeter wavelengths. The U.S., SKA development program will, in collaboration with the international radio astronomy community, aggressively pursue technology and technique development in this decade that will enable the construction of the SKA in the following decade."

Table 1 lists a few of the current SETI projects and illustrates how much the Allen Telescope Array and the SKA will improve the radio search capabilities in the coming decades. Optical SETI will also move to larger telescopes and achieve better sensitivities in the near future. With this increased search capability, our chances of detecting a signal (if any is out there) will improve dramatically. What happens if we succeed?

SETI researchers have all developed post-detection protocols for their own projects to verify any detection and eliminate the possibilities of faulty equipment and hoaxes, and they have all determined to make the discovery public as soon as possible. Any signal sent to Earth is rightly the property of all humankind, and all of our observational capabilities and collective intelligence may be needed to try to capture any encoded information and decipher it. The odds are that the signal will come from a direction that will require multiple observing facilities, in multiple countries, to achieve continuous monitoring. To prepare for the eventual discovery, the International Academy of Astronautics has prepared a position paper entitled *"A Decision Process for Examining the Possibility of Sending Communications to Extraterrestrial Civilizations: A Proposal,"* and has briefed the United Nations Committee on the Peaceful Uses of Outer Space on its provisions, suggesting that the UN committee might wish to deliberate in advance upon the issues of whether a reply should be sent, how to achieve global consensus, who will speak for Earth, and what they will say.

Today, the most cogent comment on whether our SETI endeavors will succeed, in the near future, generations from now, or never, is still the last sentence on the first paper published on this subject. "The probability of success is difficult to estimate; but if we never search, the chance of success is zero."

Figure 1.- Decision Tree for SETI Search Strategies

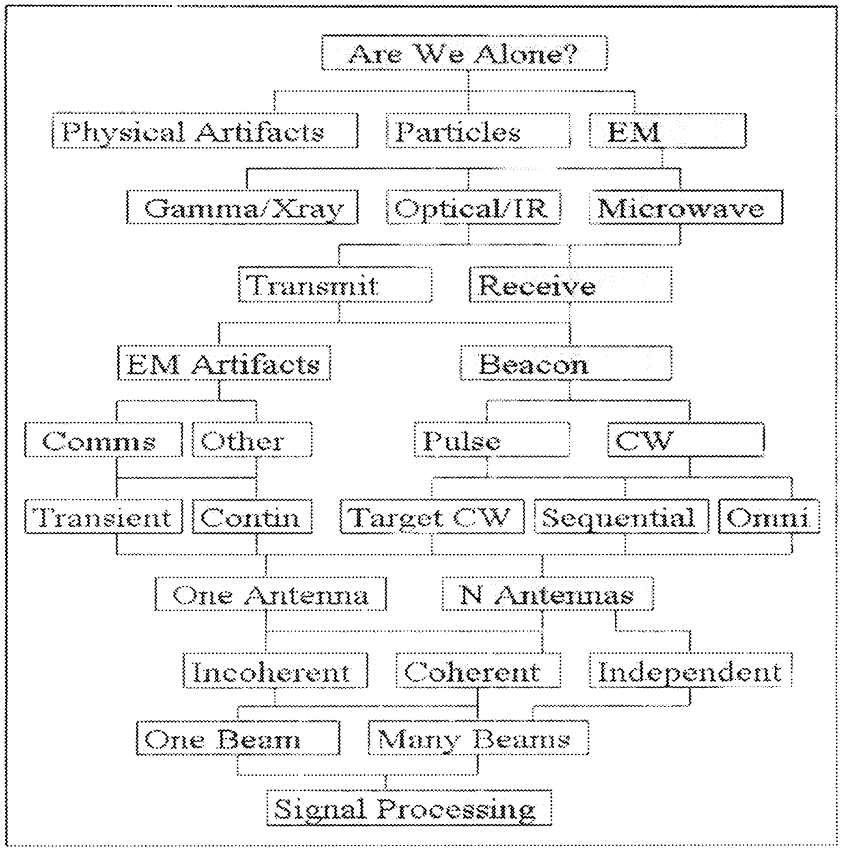


Figure 2. – Coverage of Search Space to Date

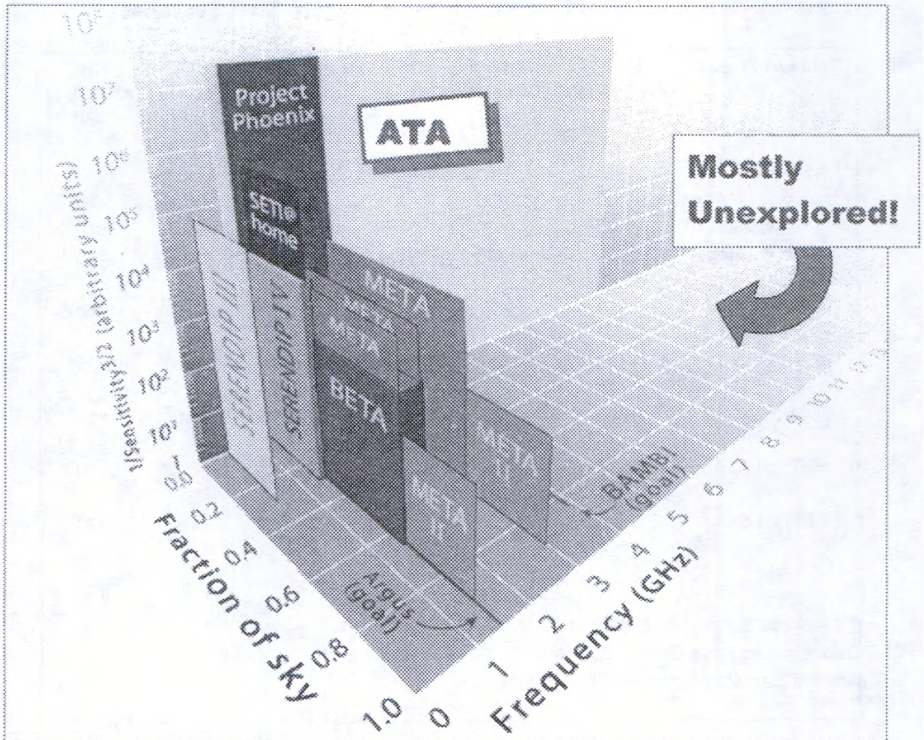


Table 1 – Sensitivities of Some Current and Future SETI Searches

Name of Project	Mean Frequency (MHz)	Frequency Coverage (MHz)	# of Stars or % of Sky	Detection Threshold (W m^{-2})	EIRP at 4 ly (W)	EIRP at 1000 ly (W)
Project Phoenix:						
Parkes	2100	1800	206 *	2×10^{-25}	4×10^{9}	2×10^{14}
NRAO 140'	2100	1800	195 *	3×10^{-25}	5×10^{9}	3×10^{14}
Arecibo	2100	1800	600 *	8×10^{-27}	1×10^{8}	9×10^{12}
SERENDIP IV	1520	200	28%	1×10^{-24}	2×10^{10}	1×10^{15}
SETI @ home	1420	2.5	28%	5×10^{-25}	1×10^{10}	5×10^{14}
BETA	1580	320	68%	1×10^{-22}	2×10^{12}	1×10^{17}
SETI on ATA	5500	9000	100,000 *	8×10^{-27}	1×10^{8}	9×10^{12}
SETI on SKA	5500	9000	1000000 *	8×10^{-29}	1×10^{6}	9×10^{10}

TV leakage signals have EIRP of 10^{7} W
Strong radars have EIRP of 10^{12} W
Arecibo planetary radar has EIRP of 5×10^{13} W