POSSIBILITY OF INTELLIGENT LIFE ELSEWHERE IN THE UNIVERSE

[REVISED OCTOBER 1977]

REPORT

PREPARED FOR THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
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LETTER OF TRANSMITTAL

U.S. HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS,
Washington, D.C.

Hon. OLIN E. TEAGUE,
Chairman, Committee on Science and Technology,

DEAR MR. CHAIRMAN: Transmitted herewith is a document prepared by Marcia S. Smith of the Science Policy Research Division of the Library of Congress, entitled, "Possibility of Intelligent Life Elsewhere in the Universe," (revised October, 1977). This document is an update of a report published in 1975. Because of completion of a 2-year study, sponsored by the Interstellar Communication Study Group for NASA, and the increasing concern with crowding of the radio spectrum, it seems appropriate to bring this singular document up to date.

As we learn more and more about ourselves and the universe we live in, the more likely it appears that intelligence beyond the bounds of our planets may exist. If we are to react rationally to such possibilities we must study and understand the knowledge which currently exists in this field. This document is a contribution to that understanding.

Sincerely,

DON FUQUA,
Chairman, Subcommittee on Space Science and Applications.

LETTER OF SUBMITTAL

THE LIBRARY OF CONGRESS,
CONGRESSIONAL RESEARCH SERVICE,
Washington, D.C., June 10, 1977.

Hon. DON FUQUA,
Chairman, Subcommittee on Space Science and Applications, Committee on Science and Technology, U.S. House of Representatives, Washington, D.C.

DEAR MR. CHAIRMAN: In response to discussions with your staff, the 1975 report "Possibility of Intelligent Life Elsewhere in the Universe" has been revised and updated, and is enclosed herewith.

The report was revised and updated by its original author, Marcia S. Smith, Analyst in Science and Technology, Science Policy Research Division. Dr. George Gatewood, Director of the Allegheny Observatory, provided information on the status of astrometry, and the NASA Ames Research Center SETI Program Office was of assistance in obtaining information about NASA efforts in this field.

Sincerely,

GILBERT GUDE, *Director.*

CONTENTS

An artistic conception of our home galaxy, the Milky Way. Note the two satellite galaxies off to the left (called the Large and Small Magellanic Clouds). Artwork by Victor Costanzo. Source: Gerrit V. Verschuur. Shape of the Milky Way. Astronomy, v. 3, Oct. 1975 : 51.

PREFACE TO THE REVISED EDITION

In the two years since the original publication of this report, several events have occurred leading to a decision by the Subcommittee on Space Science and Applications of the Committee on Science and Technology, U.S. House of Representatives to update the 1975 document. The most significant of these developments are:

1. The successful landing of two biological probes (Viking 1 and 2) on the surface of Mars, to search for evidence of life on that planet;
2. The conclusion of a two-year study sponsored by the Interstellar Communication Study Group of the National Aeronautics and Space Administration, recommending that a program to search for signals from extraterrestrial civilizations be initiated now;
3. Increased concern that by the time such a program is initiated, the radio spectrum will be so crowded that a signal from another civilization would be drowned out by Earth-generated interference (interested scientists are seeking allocation of a special part of the spectrum specifically for the search for extraterrestrial intelligence); and
4. A decision by NASA's Interstellar Commuication Study Group to substitute the acronym SETI (Search for Extraterrestrial Intelligence) for the more common CETI (Communication with Extraterrestrial Intelligence), emphasizing their intention to look for signals and decode them, not make a decision on whether or not to respond.

SUMMARY

The long-standing belief that the only intelligent life in the universe exists on our planet, Earth, is gradually disappearing. As early as the 13th century, philosophers ruminated on the possibility of other planets in the celestial void supporting intelligent life. Once it was discovered (and accepted) that Earth was not the center of the solar system, let alone the universe, speculation intensified. At first it focused on the planets of our own solar system, but current scientific thought maintains that if any life other than our own does exist in this small corner of the universe, it is of a simple biological form only, not what could be classified as intelligent. Recent estimates by some of these same scientists, however, suggest a probability of as many as 1 million advanced civilizations existing in the Milky Way galaxy alone. The Milky Way is the galaxy which contains our Sun and its solar system; astronomers calculate that there are approximately 100 billion other stars in the Milky Way, as well as 100 billion other galaxies in the universe. There are, then, 10^{22} (10,000,000,000,000,000,000,000) stars in the known universe which could conceivably have planets orbiting them, possibly supporting some type of life.

Scientists have already begun to identify methods for contacting other civilizations that might exist in the universe. Of the methods available, two categories can be identified: electromagnetic waves, and spaceships (manned or unmanned). There are advantages and disadvantages to both. Electromagnetic signals (either radio or light waves) can travel at the speed of light, but convey only small amounts of information at a time, therefore requiring very long periods of time for two-way communication. Ships can carry artifacts or passengers to communicate a more complete picture of Earth, its peoples and cultures, but according to currently accepted laws of physics, cannot travel at the speed of light (see chapter 4). In addition, technology is now available for sending or receiving electromagnetic signals, but spaceships travel at a mere fraction of the speed of light and we do not know how to alter the human life-cycle so that manned ships could travel through space without regard for our short life span. Unmanned probes have already been launched into space which carry greetings from planet Earth (Pioneer 10 and 11, Voyager 1 and 2), but it seems more than likely that technology will develop to such a point that future ships will pass these vestiges of present-day technology on their way through interstellar space, much as jets pass propeller airplanes.

There are, of course, certain risks involved in coming into contact with an alien, probably superior, intelligence, and the consequences depend in part upon whether the contact is a face-to-face encounter in which "they" have arrived at our doorstep, or if we have intercepted a radio signal from them. We have no control over the first situation, but in the latter case, we are fairly safe since there is no requirement for us to respond. Although we have been transmitting radio signals

for 40 to 50 years, only extremely sensitive receivers could detect them, so our existence may well be unknown. In intercepting a signal, then, we have the option to respond or not, and by listening to their transmissions could learn their nature and intentions toward other species. A complicating factor would develop if they wanted to deceive us by transmitting messages that appear beneficent, while their intentions were malevolent.

Possible benefits that might accrue from establishing communication include areas such as language, culture, basic science, and survival itself. We would necessarily have to be cautious in accepting any advice initially, but in the long run the possibilities are titillating. A 1971 report on a design study of a system to detect interstellar signals by Stanford University and the National Aeronautics and Space Administration commented:

> We cannot assert that interstellar contact is totally devoid of risk. We can only offer the opinion that, in all probability, the benefits greatly outweigh the risks. We cannot see that our security is in any way jeopardized by the detection of signals radiated by other life. It is when we respond to such signals that we assume any risks that may exist.[1]

To emphasize its commitment to receiving signals rather than establishing two-way communication, NASA now uses the acronym SETI, for Search for Extraterrestrial Intelligence, rather than the more common CETI, for Communication with Extraterrestrial Intelligence.

Before a major search program can be initiated, however, target planets having a strong probability of supporting intelligent life must be identified. The first step in this process, selecting those stars which have planetary companions, is the work of astronomers. There have been, in fact, several "discoveries" of planetary companions in the past, although all of these have now been questioned by other astronomers who claim that the data collection techniques were faulty. In moving or repairing a refracting telescope (the type used for these observations), the lens can shift slightly, yielding data similar to that produced by a companion (either planetary or stellar) to the star under study. It is hoped that new refractors can be designed to remedy this defect.

Scientists can currently search for signals from other civilizations with radio telescopes, but they are limited not only by the technology of the receivers, but also by interference from radio waves emanating from earthly devices, such as satellites and commercial radio and television. The frequency band which many scientists conclude is the most likely to carry messages from other intelligences (1420–1700 megahertz, or the "waterhole" region) is becoming increasingly crowded with other services. If the present pace continues, receivers may not be able to distinguish between man-made interference and a signal arriving from space, regardless of how advanced radio telescope technology becomes. If a search is to be conducted, then, either the waterhole will have to be reserved for such activities, or the receiving antennas must be located outside the zone of interference from Earth-related systems (perhaps on the far side of the Moon).

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[1] Project Cyclops: A Design Study of a System for Detecting Extraterrestrial Intelligence. Moffett Field, Calif., NASA, rev. ed., 1973: 32.

INTRODUCTION

As it was once believed that Earth was the center of the universe and all else revolved around it, so have Earthlings believed from time immemorial that we are the only intelligent life in the universe. When Copernicus demonstrated that it was Earth that revolved around the Sun and not the reverse, however, discussions on the possibility of other earths revolving around other suns attracted new followers. The history of belief in such worlds, though, is marked by ridicule and tragedy—Giordano Bruno was burned by the Church of Rome in the 17th century for his advocacy of the concept.

One of the earliest published works on the subject was written in 1728 by Bernard du Fontennelle, entitled "Plurality of Worlds".[1] His dissertation took the form of a week's conversation with a young countess, and concluded that there was indeed an excellent chance of other worlds supporting intelligent life. A century later, Alexander Copland presented arguments both in favor of and against the concept in "The Existence of Other Worlds: Peopled With Living and Intelligent Beings".[2] These works are valuable as historical references on the evolution of social thought on the subject.

Today, prominent scientists are openly and seriously studying methods to determine if there are other civilizations, and if so, how to make contact with them. The reader should note, however, that this field is quite different from the study of unidentified flying objects (UFOs). Many supporters of the thesis that there are other intelligent civilizations do not support the contention that they have visited Earth—UFOs are not discussed in this report. The paper is, instead, a synthesis of past and current thought on the possibility that there is intelligent life elsewhere in the universe, together with discussions of the possible impacts of making contact with it.

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[1] Bernard du Fontennelle. Plurality of Worlds. London, Red Lyon in Pater-Noster-Row, 1728.

[2] Alexander Copland. Existence of Other Worlds. London, J. G. & F. Rivington, 1834.

GLOSSARY

Arecibo Radio Telescope—Operated by Cornell University for the National Science Foundation, the Arecibo Radio Telescope is 1,000 feet (305 meters) in diameter with a collecting area of 20 acres (the largest in the world). In addition to performing usual radioastronomy work, Arecibo was used to transmit man's first message into space to intentionally announce our existence. See photograph on page 66.

Barnard's Star—The second nearest star system to Earth and therefore the subject of much study. In 1964 Peter van de Kamp announced the discovery of a companion to the star and for several years astronomers concluded it was a planet. Subsequent analysis of van de Kamp's data revealed a possible systematic error and there is presently no unambiguous data to suggest the presence of a planet there. Barnard's star is 6 light years from Earth.

Barycenter—The common center of gravity around which two bodies of different mass revolve. For example, the Earth-Moon system has a barycenter which is located inside the Earth because its mass is more than 80 times that of the Moon. Similarly, the Earth-Sun, Jupiter-Sun and all other two-body systems have a barycenter.

Binary Star—A system of two stars revolving around a barycenter. They are classed into three types: visual—both components can be seen with a telescope; spectroscopic—the two cannot be seen visually, but are determined by features in their spectra; and eclipsing—one of the pair eclipses the other, thus altering the perceived brightness of the star.

c—Designation for the speed of light (3×10^8 meters per second or 186,000 miles per second).

°C—designation for degrees centigrade.

CETI—acronym for Communication with Extraterrestrial Intelligence. Compare with SETI, below.

Electromagnetic Spectrum—All light and radio waves travel through space in waves and are broken down into an electromagnetic spectrum by their wavelength and frequency. The distance from the top of one wave to the top of the next is called wavelength. Frequency is the speed of light divided by wavelength, so a short wavelength is comparable to a high frequency. The entire spectrum is shown in figure G–1.

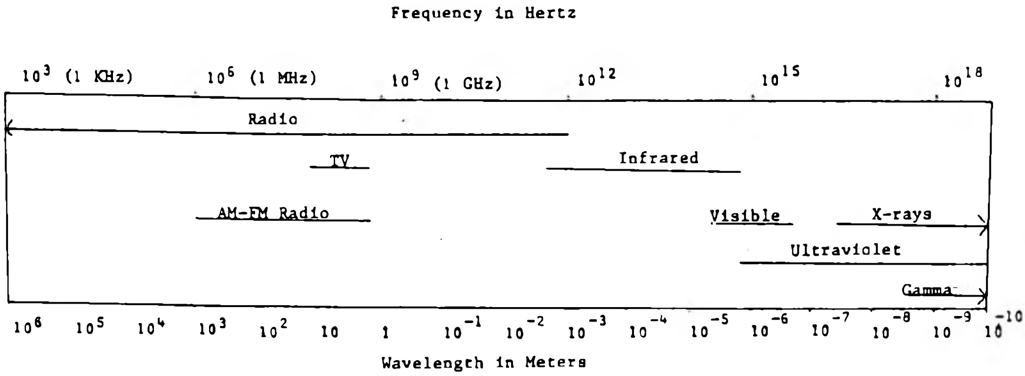


FIGURE G-1.—The electromagnetic spectrum.

Epsilon Eridani—One of two stars studied in Project Ozma. Some astronomers think there is a good chance that a planetary system developed there, although there is no proof of that theory at the present time. Epsilon Eridani is approximately 11 light years away.

Exhaust Velocity—In rocketry, the rate at which a propellant burns and throws energy out the back. It is dependent on the gas' temperature and average molecular weight. A higher temperature and lower molecular weight yields a higher exhaust velocity.

Final Mass—The weight of a rocket after all consumables have been used up; that is, the payload weight plus spent rocket casings.

Fusion—A thermonuclear reaction presently used for bombs, which perhaps can be used as a spacecraft propellant in the future. The process combines light nuclei (deuterium, or heavy hydrogen) to form helium plus energy. It should not be confused with fission, which is also used in bombs.

Galaxy—An aggregate of stars, dust and gas with a more or less definite structure, usually spiral-shaped. For most galaxies, the diameter ranges from 7,000 to 150,000 light years, with a maximum thickness 10–15 percent of the diameter. We live in the Milky Way galaxy (see Frontispiece) which is thought to be a flat disc, 600 light years thick and 100,000 light years across, with our Sun about 30,000 light years from the center. There are about 10^{11} stars in the Milky Way galaxy, and about 10^{11} galaxies in the known universe.

GHz—Abbreviation for gigahertz, or 1 billion (10^9) hertz.

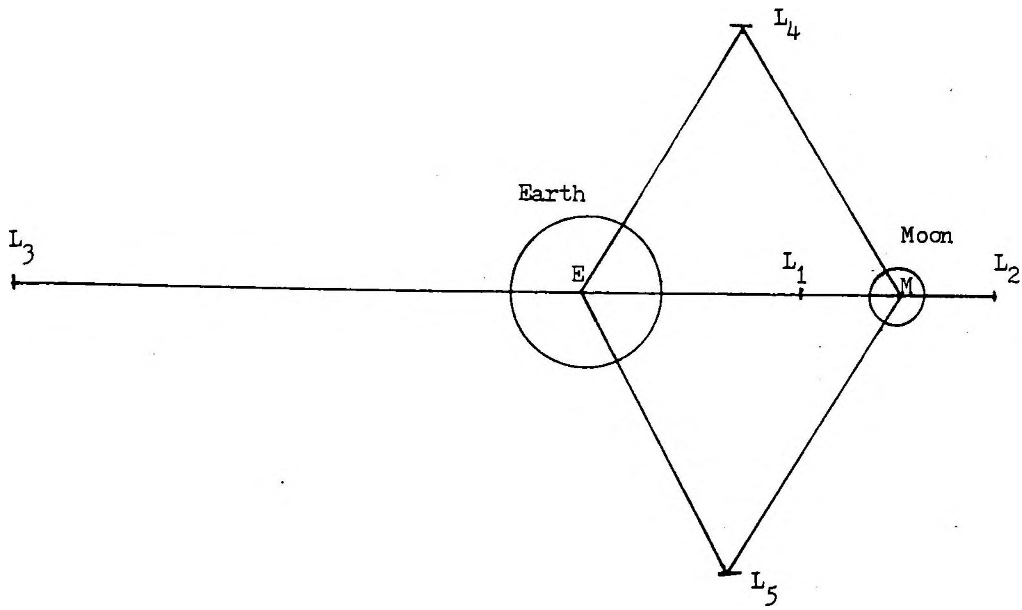
Hertz—One hertz equals one cycle per second.

Initial Mass—In rocketry, the entire weight of a rocket before launch, including all fuel, payload, and structure.

°K—Designation for degrees Kelvin. O° Kelvin is equal to absolute zero, or −273°C.

KHz—Abbreviation for kilohertz, or one thousand (10^3) hertz.

Lagrange Coordinates—Also called libration points, these are the five moving points in space identified by J. L. Lagrange where the gravitational forces of the Earth and Moon cancel each other out. An object placed at one of these points (such as a space telescope) would remain at that point rather than fall toward either body. Of the five points (depicted in figure G-2), only L_4 and L_5 are considered stable enough to be used for this purpose.



EL_4M and EL_5M are equilateral triangles, with each side approximately 384,000 kilometers (240,000 miles) long. $L_1M = L_2M$.

FIGURE G–2.—The Lagrange coordinates

Light (Speed of)—The speed of light, often designated *c*, is the speed at which an electromagnetic wave travels in a vacuum: 3×10^8 meters per second, or 186,000 miles per second.

Light Year—The distance a ray of light or radio signal travels in one year in a vacuum: 9.461×10^{12} kilometers or 5.879×10^{12} miles.

Main Sequence Stars—Stars are classified into a main sequence according to their mass, which also determines luminosity, temperature, spectral type and longevity. A star moves onto the main sequence once its internal heat and pressure become sufficient to begin the burning of hydrogen. Once the hydrogen is exhausted, the core contracts and the star turns into a supernova. For example, the hot blue giants of spectral type O spend only a few million years on the main sequence while those like our Sun (spectral type G) remain for 10 to 15 billion years.

The spectral type of a star indicates its color and temperature in the following sequence:

Spectral type:	Color	Surface temperature (degrees centigrade)
O	Very blue	50,000
B	Blue	25,000
A	Green	11,000
F	White	7,600
G_0	Yellow	6,000
G_5–K	Orange	5,100
M, R, N, S	Red	3,000–3,600

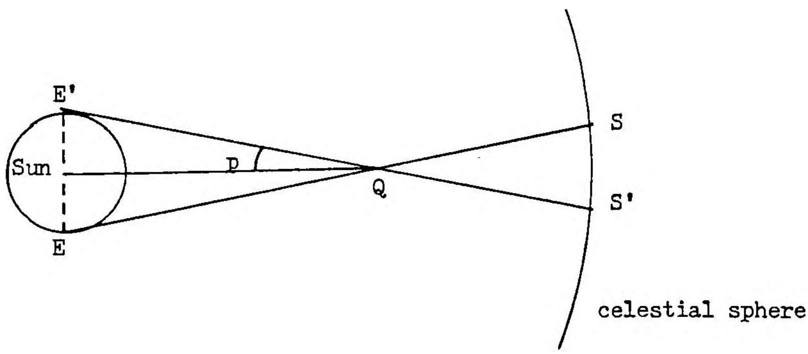
The spectral type is designated by its letter as well as being subdivided on a decimal scale so that an A_5 star would be halfway between an A_0 and F_0. Some authors use the words "early" and "late" rather than the decimal equivalents.

Mass Ratio—The ratio of initial mass to final mass. Important for determining how large a payload can be launched with how much fuel.

MHz—Abbreviation for megahertz, or one million (10^6) hertz.

Ozma—Project Ozma was a 1960 attempt to detect radio transmissions from other civilizations; the first such program. Directed by Dr. Frank Drake at the National Radio Astronomy Observatory in Green Bank, West Virginia, the stars Tau Ceti and Epsilon Eridani were studied. A follow on effort, Ozma II, was conducted at NRAO from 1972 to 1975.

Parsec—The distance to a star having a parallax of one second of arc (parallax second) or 3.26 light years. In a circle there are 360 degrees, each of which can be divided into 60 minutes, which in turn can be divided into 60 seconds; one of these is called a second or arc. Referring to figure G–3, angle "p" is called a star's parallax. For this angle to equal one second of arc, the star must be 3.26 light years away. This distance, the parsec, has become a standard astronomical unit of distance.



The star Q is observed at six month intervals from the Earth. At position E, the star appears on the celestial sphere at S. Six months later the Earth based observer is at E' and the star is observed to be at S'. Using the distance from E to the Sun as a base (one astronomical unit), a star at Q would have to be 3.26 light years (one parsec) away in order for angle p to equal one second of arc. Angle p is called the star's parallax.

FIGURE G–3

Photometer—An instrument for measuring light intensity, especially in determining the relative intensity of different lights.

Pioneer 10—The first space probe to reach the planet Jupiter, and will eventually leave the solar system. On board is a plaque showing its home port of Earth and basic information about humans. It is our first attempt to contact other intelligent life.

Radiometer—A device for measuring the intensity of energy radiated, as from a planet.

Reflecting Telescope—A telescope which uses a mirror to reflect light rays back to a focus. The mirror is a piece of glass coated with a

highly reflective layer of silvering material, usually silver or aluminum. The glass is shaped like a parabola so that the parallel light rays are reflected to a common focus. This type of telescope is free from the chromatic aberrations of refractors, but is not as precise in studying a specific star. The largest fully operational reflector is the 200-inch Hale telescope at Mount Palomar, California.

Refracting Telescope—A telescope which uses a lens to bend and focus light onto a photographic plate or eyepiece. Although they are generally more expensive than reflectors because of the precision needed for the lens, and suffer from chromatic aberration (different colors of the spectrum are bent to different degrees, so do not focus on the same spot), they are more precise for studying characteristics of a specific star. The largest refractor is the 40-inch instrument at Yerkes Observatory, Williams Bay, Wisconsin.

SETI—Acronym for Search for Extraterrestrial Intelligence. Compare with CETI, above.

Solar System—A group of objects orbiting a common star and whose motions are primarily determined by the star. Our solar system consists of the Sun, the nine planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto) and their natural satellites, the asteroids, comets, meteoroids, and dust and gas.

Tau Ceti—One of the two stars studied in Project Ozma. Some consider it a good candidate for having planets on which a civilization could evolve. It is approximately 11 light years distant.

Terraforming—The process of changing the environment of a planet to make it suitable for habitation by man. For example, building a protective dome on the Moon to provide atmosphere and temperatures for man is a limited kind of terraforming.

Variable Star—A star whose energy output (and brightness) is not constant. There are two classes: pulsating—the star rhythmically swells and shrinks; and explosive—the star periodically expels gusts of gas (includes those that become supernovae).

Viking—The first biological space probe to land on another planet (Mars).

CHAPTER ONE

LIFE IN OUR SOLAR SYSTEM

For decades man's imagination has been filled with stories of life on other planets in our solar system, from H. G. Wells' *War of the Worlds* to Arthur C. Clarke's *2001: A Space Odyessy*. Mars has always held a special place in these dramas, spurred by such "scientific" findings as the discovery of canals on that planet, thought to have been constructed by an advanced civilization living there.

The foundation of this belief was a series of observations made by the Italian astronomer Giovanni Schiaparelli during Mars' closest approach to Earth (56,000,000 kilometers) in 1877, and again from 1881–82. He sighted a number of dark lines which seemed to form patterns on the planet's surface, which he termed "canali" for channels. His map of these lines was used as a standard illustration in textbooks at the time. When translated into English, however, "canali" became canals, with the attendant connotation of being engineering feats rather than natural phenomena.

Although Schiaparelli did not attempt to explain the significance or origin of the lines, American astronomer Percival Lowell did, concluding they were canals built by a race of intelligent beings. Knowing that it was unlikely that the canals would themselves be visible from Earth, Lowell explained the lines as vegetation growing on either side of each canal.

Lowell nurtured the foundling belief that a super civilization existed on Mars, and expounded on their form of government and indigenous social and environmental problems. His theory was supported by a number of eminent astronomers (including Schiaparelli), but was also opposed by many equally prominent astronomers who reported that they could not see the many lines depicted in Lowell's detailed map of Mars. The heated debate on this issue subsided only after Lowell's death in 1916, and with subsequent advances in the resolving power of telescopes, it became clear that his network of canals did not exist in reality. By this time, however, the concept had taken root in science fiction circles, and tales of Martians and their escapades dominated the literature.

Although there are few, if any, scientists who now believe that intelligent life exists on Mars (or any planet in the solar system other than Earth), many hope that basic life forms may, such as simply replicating chemicals or bacteria. The search for such life is an ongoing project. Mars has been an especially tempting target, and the first planetary biological probes, Viking 1 and 2, were sent to that planet in 1975.

A. Mars

Of the sixteen probes sent to Mars by the United States and Soviet Union since 1962 (summarized in figure 1–1), three were critical in shaping our perception of Mars: Mariner 9 and Viking 1 and 2.

FIGURE 1-1
[1]
MARS PROBES

NAME	COUNTRY	LAUNCH DATE	PRIMARY MISSION	RESULTS/COMMENTS
Mars 1	USSR	Nov. 1, 1962	Unknown	Communications failed. Passed planet at 193,000 kilometers.
Mariner 3	US	Nov. 5, 1964	Flyby/photographic	Communications failed. Shroud failed to jettison, throwing probe off course.
Mariner 4	US	Nov. 28, 1964	Flyby/photographic	Returned pictures and data. Passed planet at 9,850 km.
Zond 2	USSR	Nov. 30, 1964	Unknown	Communications failed. Passed planet at 3,200 km.
Mariner 6	US	Feb. 24, 1969	Flyby/photographic	Returned pictures. Passed planet at 3,200 km.
Mariner 7	US	Mar. 27, 1969	Flyby/photographic	Returned pictures and data. Passed planet at 3,500 km.
Mariner 8	US	May 9, 1971	Orbiter/photographic	Failed due to launch vehicle malfunction.
Mars 2	USSR	May 19, 1971	Orbiter-lander/ geophysical	Orbiter achieved orbit; lander destroyed on impact with the planet.
Mars 3	USSR	May 28, 1971	Orbiter-lander/ geophysical	Orbiter achieved orbit and returned data. Lander destroyed after 20 seconds on planet's surface, possibly due to high winds.
Mariner 9	US	May 30, 1971	Orbiter/photographic	Achieved orbit. Sent back excellent photographs and other data.
Mars 4	USSR	July 21, 1973	Orbiter	Paired with Mars 6. Missed planet by 2,000 km.

FIGURE 1-1 (continued)

NAME	COUNTRY	LAUNCH DATE	PRIMARY MISSION	RESULTS/COMMENTS
Mars 5	USSR	July 28, 1973	Orbiter	Paired with Mars 7. Achieved orbit.
Mars 6	USSR	Aug. 5, 1973	Lander/geophysical	Paired with Mars 4. Failed at touchdown, but transmitted data during descent.
Mars 7	USSR	Aug. 5, 1973	Lander/geophysical	Paired with Mars 5. Missed planet.
Viking 1	US	Aug. 20, 1975	Orbiter-lander/ biological	Successfully landed on the planet on July 20, 1976. Transmitted first pictures of the surface, performed scientific experiments. Still operational as of September 1977.
Viking 2	US	Sept. 9, 1975	Orbiter-lander/ biological	Identical spacecraft to Viking 1. Still operational as of September 1977.

1 Chart does not include some USSR launches in the early 1960s and 1969 that were unsuccessful and never officially designated as Mars' flights. For complete description of the Soviet planetary program, see: U.S. Congress. Senate. Committee on Aeronautical and Space Sciences. Soviet Space Programs, 1971-75. Committee Print. Washington, U.S. Govt. Print. Off., 1976: Vol. I, Ch. 2.

During the decade of the 1960's, U.S. planetary spacecraft focused on flyby missions, in which spacecraft fly past a planet rather than attempting to go into orbit, and take pictures as they pass. Mariners 4, 6 and 7 successfully took pictures of about 10% of the Martian surface. The Russian Mars probes were considerably less successful in the 1960's; none of them returned data about Mars.

The 1970's is the period in which we are truly beginning to acquire hard knowledge about Mars. In 1971, two American and two Russian Mars probes were launched. The U.S. spacecraft, Mariner 8 and Mariner 9, were a pair of vehicles designed to enter Martian orbit and transmit photographs of the surface. Mariner 8's launch vehicle suffered a malfunction and the mission was lost; Mariner 9, however, was launched successfully and reached Mars in late 1971. Although dust storms obscured the surface for the first two months of its time in Martian orbit, the spacecraft did transmit photographs of what later was discovered to be the tops of huge volcanoes. Once the dust storms abated, Mariner 9 returned astounding photographs of the surface, revealing it to be quite unlike what scientists had anticipated. As explained in NASA's *Mars as Viewed by Mariner 9:*

> Soon it became apparent that almost all generalizations about Mars derived from Mariners 4, 6 and 7 would have to be modified or abandoned. The participants in earlier flyby missions had been victims of an unfortunate happenstance of timing. Each earlier spacecraft * * * had chanced to fly by the most lunar-like parts of the surface, returning pictures of what we now believe to be primitive cratered areas. * * * It was almost as if spacecraft from some other civilization had flown by Earth and chanced to return pictures only of its oceans.[1]

The Russian attempts of 1971 were directed toward landing a geophysical probe on the surface of the planet, as were their missions in 1973. Of the six spacecraft sent to Mars during this time, only two (Mars 3 in 1971 and Mars 6 in 1973–74) achieved any success at all, and this was only in obtaining data on the Martian atmosphere during

[1] National Aeronautics and Space Administration. Mars as Viewed by Mariner 9. Washington, D.C., National Aeronautics and Space Administration, 1976. NASA SP-329 (Revised). Preface [n.p.]

descent. Both landers ceased communication after reaching the surface of the planet; Mars 3 transmitted about 20 seconds of photographs, not enough for even one frame, while Mars 6 sent no data from the surface.

In 1975, the United States marked its first attempt to land a probe on the surface of another planet by the launch of two Viking spacecraft to Mars. Unlike their Soviet predecessors, these were biological probes, designed to investigate the possibility of life existing on the red planet.

Each spacecraft consisted of two parts: an orbiter and a lander. The orbiter-lander combination travelled through space as a single unit, separating only after Martian orbit had been achieved, and a safe landing site determined. Discussions concerning what experiments should be carried on this type of probe had been underway at NASA for over fifteen years,[2] and thirteen experiments were finally chosen, including three from the orbiter, eight from the lander, and two from both, as the following list indicates:

Orbiter

Atmospheric Water Vapor Mapping.
Thermal Mapping.
Orbiter Imaging.

Lander

Molecular Analysis.
Lander Imaging.
Biology.
Inorganic Chemistry Analysis.
Meteorology.
Seismology.
Physical Properties.
Magnetic Properties.

Both

Radio Science.
Charged Ion and Electron Particle Measurements.

[2] See: Freeman Quimby. Concepts for Detection of Extraterrestrial Life. Washington, D.C., National Aeronautics and Space Administration, 1964.

To accomplish these investigations, Viking carried a vast amount of scientific equipment, including:

1. Cameras (orbiter and lander).
2. Infrared spectrometer and infrared radiometer (orbiter).
3. Gas chromatograph mass spectrometer (lander).
4. Microorganism detectors including pyrolytic release, labeled release, and gas exchange experiments (lander).
5. X-ray fluorescence spectrometer (lander).
6. Seismometer (lander).

Both spacecraft were sterilized before leaving Earth to insure that if any life forms were detected, they would be of Martian origin, and to make certain that Earth bacteria did not contaminate Martian soil.

Viking 1 arrived at Mars on June 19, 1976, with landing scheduled for July 4, the 200th anniversary of the United States of America. Uncertainty over the safety of the proposed landing site in the Chryse basin led NASA to delay landing until a safer site could be found. On July 20 (which coincidentally was the seventh anniversary of man's landing on the Moon), Viking 1 landed in the Chryse Plains. The lander performed flawlessly during descent, and returned the first pictures of Mars shortly after touchdown. The photographs showed that Mars is indeed red, as it appears through Earth-based telescopes (probably the result of iron oxide, or rust, in the rocks which cover both Viking landing sites). The sky is pink, caused by particles of the red surface dust suspended in the atmosphere. The landing site was strewn with small rocks, the largest being about 3 meters wide and 1 meter high.

Viking 2 went into Martian orbit on August 7, 1976, and the Utopia Plains were finally selected as its landing site. The site choice had been delayed pending the outcome of Viking 1's landing attempt. When that craft had safely come to rest on the surface of Mars, scientists chose a site where they expected a greater concentration of water, suggesting a greater probability of life development. Judging from orbital pictures, the Utopia Plains appeared to be covered with sand-like dunes.

When the orbiter and lander separated on September 3, the orbiter apparently flipped over, causing its high gain antenna to be pointed away from Earth, and communication with the mission was virtually lost, with the exception of a very low gain engineering channel. The lander continued to the surface with its prerecorded set of computer instructions, and landed safely on the surface. The engineering channel relayed a fourfold increase in signal strength, a change that could only have occurred if the lander had successfully reached the surface in an operational condition. Thus, mission controllers knew the lander was still intact, and proceeded to work out the problem with the orbiter. The direction of the high gain antenna was finally corrected about 12 hours later, and the photographs taken automatically by the lander after touchdown were relayed back to Earth. Scientists were quite surprised to find that instead of the rolling dunes they had expected, they had once again set down amidst small, scattered rocks.

The two Vikings discovered many things about Mars. The orbiters confirmed for the first time that the poles of Mars are covered by water ice, not carbon dioxide ice as previously theorized, and sent back fascinating information about Mars' two moons, Phobos and Deimos.

Phobos especially revealed some interesting markings, which appeared as though a giant hand had scratched the surface with its fingernails. These parallel lines, called striations, were not readily accounted for, although speculation includes shockwaves from impact with a meteor which may also have ripped out part of the moon (a large crater is evident at one end of the irregularly shaped body), or it may have collided with debris scattered in another portion of Mars' orbit.

The landers measured the atmosphere and showed traces of both argon and nitrogen. The significance of these findings was summarized by NASA's Associate Administrator for Space Science, Noel Hinners:

> From the measurement of argon and nitrogen in the atmosphere, we can deduce that Mars had a slightly more massive atmosphere in the past, but that much less total outgassing has occurred on Mars than on the Earth or Venus. In other words, Mars may still be developing its atmosphere, leading one to speculate that Mars may become more Earthlike in future epochs.[3]

Viking's primary mission, though, was to determine whether indigenous life exists on Mars. Unfortunately, no unambiguous data was discovered that can answer that crucial question. Although scientists found what could be considered evidence of life, they could not find evidence of death. Since we know only of finite life spans, the lack of "bodies" led some scientists to suggest that the indications of life were in fact, some new, unknown, exotic chemistry unrelated to life processes. Repeated experiments with both Viking 1 and 2 were unable to conclusively answer the question. By the end of the first phase of Viking exploration (November 1976, when communication with the probes was lost as Mars went behind the Sun), the Viking science team reflected on these inconclusive results in a NASA press conference. The four participants were: Dr. Gerald Soffen, NASA Langley Research Center, Viking Project Scientist; Dr. Harold Klein, NASA Ames Research Center, Leader of the Viking Biology Team; Dr. Klaus Biemann, Massachusetts Institute of Technology, Leader of the Viking Molecular Analysis Team; and Dr. Carl Sagan, Cornell University, Lander Imaging Team. In answer to a question from correspondent Kalb, the four scientists responded in this manner:

KALB. I've been a little overwhelmed obviously by the nature of the discussion. I wonder if at the risk of repetition for you, but for the purpose of simplification for me, if you would all individually take on the question of whether you feel, on the basis of the experiments that have been revealed, and data revealed so far, whether there is conclusively life at present or life in the past. And I wonder if we could begin with Dr. Klein.

KLEIN. Well, let me try to answer that first. I would say that on the basis of incomplete evidence which is where we are today, we cannot say conclusively that there is life on Mars. I would also say that we cannot say conclusively that there is not life on Mars.

SOFFEN. I would like to not only support that, but give you some feeling for the fact that none of these scientists have volunteered to go home. Nobody has decided that he is not [sic] longer interested. Every single one of them want to come and get their data. That must be a sign of what their feelings are.

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[3] U.S. Congress. House. Committee on Science and Technology. Subcommittee on Space Science and Applications. 1978 NASA Authorization. Hearings, Sept. 14, 15, and 16, 1976. Washington, D.C., U.S. Govt. Print. Off., 1977, pp. 64, 66.

BIEMANN. I will give you a more straight answer. My feeling is that experiments to date have not proven the presence of living systems at the two landing sites. The data are explainable in terms of nonliving chemistry.

However, I feel that they have by no means excluded the presence of nonterrestrial biochemistry at those places, or even more terrestrial-like living systems at other areas of the planet.

SAGAN. Well, in my presentation, I thought I said that we are presenting models to try to explore the extremes of the interpretation of the data, and that there is no demonstrated nonbiological activity, explaining in detail, explaining the rich detail. All of us have promising ideas about how to do it, and there is no biological explanation, which in that same richness of detail, can explain in a likely way, the results.

And therefore, the word conclusively that's used is much too strong for this preliminary and pioneering moment for the search for life on another planet.

* * *

My feeling is that on a question of this importance, it is too early to make up one's mind. You have to have extremely good data, an extremely clearcut interpretation before I think you would want to commit yourself to that. And what I would urge on you is an increased tolerance for ambiguity.[4]

Communications with the Viking probes were reinstated once Mars moved from behind the Sun. In the six months following the press conference, the biology experiments on both landers continued to operate and produced no new evidence that could clarify the situation. In May 1977, supplies exhausted, the biology experiments on both landers were terminated: Viking 1 on May 30, Viking 2 on May 28. Both probes continue to send back other data about Mars, including meteorological and geophysical information (as of September 1977).

It will be left to future Martian probes to make further experiments in order to determine whether there is or is not life on Mars. Proposals for these future missions include a Mars rover, which would be capable of moving about on the surface via treaded wheels, while performing experiments similar to those of the two Vikings. Another proposal is for a sample return mission in which a soil sample would be collected by an unmanned probe and then launched back to Earth (much as the Russians retrieve lunar samples). There is, of course, the possibility of sending men to Mars as well.

In pondering the Viking findings, it would serve well not to lose sight of the problems that would be encountered by another civilization attempting to determine if there is life on Earth. If their two probes were to land in the Sahara desert and the Antarctic (or in the Sahara and Death Valley), they would get a very different picture of life on Earth than what exists in verdant and settled places. As demonstrated by the Viking 2 experience, it was not possible to determine all characteristics of the Martian surface even from orbit: the scientists landed Viking 2 in the Utopia Plains because they expected to find dunes, yet the site was in fact very similar to that where Viking 1 set down.

It seems clear that the scenarios painted by Percival Lowell and H. G. Wells are far from the truth, but we still do not know what that truth is. That could only be determined by future missions to Mars.

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[4] National Aeronautics and Space Administration. Viking News Conference. Washington, D.C., NASA, Nov. 9, 1976, pp. 71–74.

B. Other Planets, Their Moons, and the Asteroids

The major bodies of our solar system are the nine planets and their moons (see figure 1–2), and the asteroids, which lie primarily between the orbits of Mars and Jupiter. We know that Earth has an advanced civilization, and it seems apparent that Mars does not (although basic life forms may dwell there). Neither Earth's moon, nor the two moons of Mars have atmospheres, so life probably would not develop there (analysis of lunar soil samples gathered by both the United States and Soviet Union confirm the opinion that there is no life on our Moon). But what about the other seven planets and their 30 satellites, or the asteroids? Could life exist there?

FIGURE 1-2

PLANETARY DATA

PLANET	MEAN DISTANCE FROM SUN (millions of kilometers)	(AU)*	EQUATORIAL DIAMETER (kilometers)	MEAN TEMPER-ATURE**	PERIOD OF ROTATION	PERIOD OF REVOLUTION	NUMBER OF KNOWN MOONS	LARGEST MOON (diameter in kilometers
Mercury	57.9	0.387	4,880	350 (S) Day -170 (S) Night	59 days	88 days	0	not applicable
Venus	108.2	0.723	12,104	-33 (C) 480 (S)	243 days retrograde	224.7 days	0	not applicable
Earth	149.6	1.000	12,756	22 (S)	23 hours 56 minutes	365.26 days	1	Moon (3,476)
Mars	227.9	1.524	6,787	-23 (S)	24 hours 37 minutes	687 days	2	Phobos (25)
Jupiter	778.3	5.203	142,800	-150 (C)	9 hours 51 minutes	11.86 years	13	Ganymede (5,270)
Saturn	1,427.0	9.539	120,000	-180 (C)	10 hours 14 minutes	29.46 years	10	Titan (5,800)
Uranus	2,869.6	19.180	51,800	-210 (C)	11 hours retrograde	84.01 years	5	Titania (1,800)
Neptune	4,496.6	30.060	49,500	-220 (C)	16 hours	164.8 years	2	Triton (6,000)
Pluto	5,900.0	39.440	6,000?	-230 (?)	6 days 9 hours	247.7 years	0	not applicable

* AU = astronomical unit, or the distance from the Sun to Earth.
**Mean Temperature at visible surface in degrees celsius. S = solid; C = clouds.
Source: Carl Sagan. The Solar System. Scientific American, v. 233, Sept. 1975: 26.

If one accepts the premise that an atmosphere, however tenuous, must be present for life to develop, there are eight other places in our solar system to consider: Mercury, Venus, Jupiter and its moon Io, Saturn and its moon Titan, Uranus and Neptune. The ninth planet, Pluto, does not have an observable atmosphere.

Although astronomers have studied the solar system for centuries, unmanned space probes have provided the best, detailed information currently available. As summarized in figure 1–3, in addition to Mars, U.S. probes have been to Mercury, Venus and Jupiter (with Pioneer 11 scheduled to encounter Saturn in 1979), while Soviet probes have visited Venus. These missions have fundamentally changed our Earth-bound perceptions of the planets in many cases, as shown by the following discussion.

1. Mercury.—Mariner 10's visits to Mercury in 1973 and 1974 provided the first indications that the planet has an atmosphere (although it is less than 0.1% as dense as Earth's) composed of argon, neon and helium, as well as a weak but measureable magnetic field. The probe also sent back the first photographs of Mercury's surface, revealing it to be somewhat similar to the Moon: meteor impact craters interspersed with plains, or maria.

Surface conditions on Mercury have been described as the harshest of any planet in the solar system. The temperature extremes noted in figure 1–2, coupled with the large amount of solar radiation received by the planet due to its proximity to the Sun, makes the possibility of life virtually negligible.

2. Venus.—Often described as Earth's sister planet, Venus has about the same size, density and mass as Earth. The similarity ends there, however, for Venus is enshrouded by a ubiquitous cloud which creates a "greenhouse effect", where energy arriving from the Sun cannot be reradiated back into space. This creates high surface temperatures (up to 500°C) and pressures (over 90 times that of Earth). It also rotates in a direction opposite to Earth, called "retrograde rotation."

Most of our current knowledge about Venus is based on data collected by Russian space probes (see figure 1–3). Venera 9 and 10, the two most recent Venus probes, sent back the first photographs of the Venusian surface in 1975, revealing a planet quite unlike what scientists had expected. These probes invalidated two significant beliefs about Venus: that the atmosphere's density would prevent over 90 percent of the incident sunlight from reaching the surface; and that erosion from the extreme surface conditions would make the surface smooth and sandy.

FIGURE 1-3

MERCURY, VENUS, JUPITER AND SATURN PROBES [1]

NAME	COUNTRY	LAUNCH DATE	PRIMARY MISSION	RESULTS/COMMENTS
Venera 1	USSR	Feb. 12, 1961	Venus	Communications failed; passed Venus at 100,000 km.
Mariner 1	US	July 22, 1962	Venus flyby	Destroyed at 160 km altitude by range safety officer.
Mariner 2	US	Aug. 27, 1962	Venus flyby	Passed Venus successfully at 34,853 km.
Zond 1	USSR	Apr. 2, 1964	Venus	Communications failed; passed Venus at 100,000 km.
Venera 2	USSR	Nov. 12, 1965	Venus flyby	Communications failed; passed Venus at 24,000 km.
Venera 3	USSR	Nov. 16, 1965	Venus hard lander	Communications failed; struck Venus 450 km. from visible center.
Venera 4	USSR	June 12, 1967	Venus hard lander	Returned direct readings of Venusian atmosphere to 25 km. altitude.
Mariner 5	US	June 14, 1967	Venus flyby	Returned data; passed Venus at 4,094 km.
Venera 5	USSR	Jan. 5, 1969	Venus hard lander	Returned readings of Venusian atmosphere to near surface.
Venera 6	USSR	Jan. 10, 1969	Venus hard lander	Returned readings of Venusian atmosphere to near surface.
Venera 7	USSR	Aug. 17, 1970	Venus soft lander	Landed successfully and returned data on atmosphere and surface of Venus. First soft landing on Venus.

FIGURE 1-3 (continued)

NAME	COUNTRY	LAUNCH DATE	PRIMARY MISSION	RESULTS/COMMENTS
Pioneer 10	US	Mar. 3, 1972	Jupiter flyby	Successfully returned first closeup photos of Jupiter. Currently on course out of solar system, and returning data on interplanetary void.
Venera 8	USSR	Mar. 27, 1972	Venus soft lander	Returned atmospheric data; landed successfully and performed remote control soil sample analyses.
Pioneer 11	US	Apr. 6, 1973	Jupiter/Saturn flyby	Successful encounter with Jupiter, returned photos. Currently enroute to Saturn.
Mariner 10	US	Nov. 3, 1973	Venus/Mercury flyby	Returned pictures of both planets; first photos of Mercury.
Venera 9	USSR	June 8, 1975	Venus soft lander	Landed successfully; returned first pictures of surface.
Venera 10	USSR	June 14, 1975	Venus soft lander	Landed successfully; returned pictures of surface.
Voyager 2	US	Aug. 20, 1977	Jupiter/Saturn flyby	Enroute to Jupiter.
Voyager 1	US	Sept. 5, 1977	Jupiter/Saturn flyby	Enroute to Jupiter. May be targeted for Uranus after Saturn encounter.

[1] Chart does not include several Soviet launches which are thought to be planetary failures, but were never announced as such by the Soviet Union. For complete discussion of the Soviet programs see: U.S. Congress. Senate. Committee on Aeronautical and Space Science. Soviet Space Programs, 1971-75. Committee Print. Washington, U.S. Govt. Print. Off., 1976: Vol. I, Ch. 2.

The two Venera probes, prepared for the anticipated dim lighting conditions, carried spotlights to enable the cameras to take clear photographs; they were never needed. Instead, the surface was found to be about as bright as Moscow on a cloudy summer day. Even more surprisingly, instead of a smooth, sandy surface, both Veneras found individual rocks or outcroppings which had not been eroded away; indeed, the rocks had very sharp edges. Russian project scientist Boris Nepoklonov commented:

> We thought there couldn't be rocks on Venus [because] they would all be annihilated by constant wind and temperature erosion, but here they are, with edges absolutely not blunted. This picture makes us reconsider all our concepts of Venus.[5]

These observations led scientists to conclude that instead of the old, dying planet they previously envisioned, Venus is young and evolving. Mikhail Marov, a Soviet paleontologist, remarked:

> This is documental evidence that in the scale of evolution, the planet Venus should be placed with the young, still living planets. The sharp edges of the stones, which are characteristic of the panorama from Venera–9, clearly speak in favor of tectonic activity on the planet.[6]

The Venusian atmosphere consists primarily of carbon dioxide, and its clouds are thought to be comprised of such corrosive compounds as sulfuric acid. These conditions, together with the high pressure and temperature of the surface, make the development of life on Venus unlikely, at least in this stage of its evolution.

3. Asteroids.—There are thousands of asteroids, ranging in size from hundreds of kilometers in diameter to a particle of sand. Most asteroids lie in a belt between the orbits of Mars and Jupiter, although a few have irregular orbits which carry them inside the orbit of Mercury, while others (the Trojans) lie in the orbit of Jupiter. It is thought that the asteroids are either debris from a planet that was pulled apart by the gravitational influence of Jupiter, or the raw material for a planet that was prevented from accreting by that same influence. The largest asteroid, Ceres, is 955 kilometers in diameter, more than twice the size of the next largest, Pallas. Atmospheres have not been detected on any of the asteroids; they are unlikely candidates for life evolution.

4. Jupiter and Io.—Next is Jupiter, the largest planet in the solar system. Following the first visits to Jupiter by planetary probes, Pioneer 10 and 11, a model of the planet was constructed which proposes that the planet has a small, rocky core, surrounded by two layers of liquid hydrogen and an atmosphere. The core is speculated to have temperatures about 30,000° K. According to the model, the layer closest to the core consists of liquid metallic hydrogen and extends about 46,000 kilometers from the center of the core. Temperatures here are thought to be around 11,000° K, and pressures more than three million times that on Earth.

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[5] Venus Observed. Time, Nov. 3, 1975: 63–64.

[6] David A. Brown. Data Shows Venus Young, Evolving Planet. Aviation Week and Space Technology, Nov. 3, 1975: 19.

The second layer is postulated to be liquid molecular hydrogen, extending 24,000 kilometers past the first layer. The atmosphere, which is thought to rise 1,000 kilometers above this second layer of hydrogen, has been shown spectroscopically to consist of hydrogen, helium, ammonia, methane, and water.

Since we cannot see through Jupiter's cloud layer, the model of the interior cannot be proven as yet. One interesting known fact is that Jupiter radiates more heat than it receives from the Sun, indicating that it has an internal heat source. Two theories to explain this anomaly are that the planet is shrinking as it cools and gravitational energy is being converted into heat at the core and circulated up into the atmosphere by convection currents, or that the energy is left over from the formation of the planet billions of years ago.

Such a scenario would seem inhospitable to life, yet some scientists are optimistic that organisms might evolve in the more temperate regions of the atmosphere. The four elements which, together with abundant energy, are thought necessary for formation of basic building blocks of life (such as amino acids) have been observed in the Jovian atmosphere: ammonia, hydrogen, methane, and water. Particles, both liquid and solid, are also present and could provide protected areas for the development of organic life. A factor which could impede or prevent such development is the circulation of the atmosphere, which could carry organisms into hotter regions where they might be destroyed. Something which could favor life is the relative abundance of the raw materials for life, so that even if a substantial proportion of organisms were destroyed by transportation to hotter climes, a good number might still survive.

Jupiter has 13 known moons (reports of a 14th and 15th have not yet been confirmed), only one of which is known to have an atmosphere Io. Although scientists had suspected that a sparse atmosphere existed around that satellite, it was only confirmed through experiments with Pioneer 10. Sodium, potassium and iodized sulphur have been identified in Io's atmosphere.

Io is one of the four "Galilean" satellites discovered by Galileo in 1610; none of the other three (Europa, Callisto and Ganymede) are known to have atmospheres, although readings of Ganymede do not preclude that possibility. Io has a diameter of about 3,600 kilometers, travels around the planet every 1.77 days in an orbit with a radius of 421,600 kilometers, and its high temperature is thought to be about −133°C. Surface pressure on Io is estimated at only one billionth that of Earth's. Conditions are not thought promising for the development of life on this satellite.

5. Saturn and Titan.—Saturn is the second largest planet in the solar system, and is thought to resemble Jupiter, only it is colder since it is much further from the Sun. The first unmanned probe will not reach Saturn until 1979 (Pioneer 11).

Until 1977, Saturn was thought to be the only planet with a system of rings encircling the planet, although new data show that Uranus, too, is a ringed planet. The rings are thought to consist either entirely of ice, or have rocky cores surrounded by ice. The rings might be debris from a moon that was pulled apart by Saturn's gravitational force, or the matter which would have formed a moon except for that influence; thus their formation may not be dissimilar from that of the asteroids.

Current models postulate that Saturn has a rocky core about 20,000 kilometers in diameter, surrounded by a 5,000 kilometer shell of ice and an 8,000 kilometer layer of metallic hydrogen. The atmosphere which surrounds that planet has been spectroscopically observed to contain methane and hydrogen. Scientists suspect that ammonia is also present on Saturn, as it is on Jupiter, but that the lower temperatures cause it to exist in a solid layer so far down in the clouds that it cannot be detected from Earth. Like Jupiter, Saturn radiates more heat than it receives from the Sun, although since Saturn is so much further out, that amount of heat is considerably less (about one fifth that of Jupiter). With such cold temperatures, the possibility of life seems bleak.

Saturn has ten known moons, one of which, Titan, has a dense atmosphere that was first discovered in 1944; its main constituents appear to be methane and hydrogen. The satellite's surface is thought to be covered by ice consisting of water and methane at a temperature of about −148°C, and with a surface pressure between one and one-tenth Earth's surface pressure. Scientists think that if there is any thermal or volcanic activity on Titan, temporary pools of warm water might exist which could provide the medium for development of life. Physicist Donald M. Hunten has commented: "Titan is a body unlike any other we know of. It is neither like one of the inner planets nor like one of the giant outer planets but is kind of a hybrid. Its close exploration cannot fail to be highly rewarding."[7]

Our knowledge of Saturn and its moons is rudimentary at the present time, and just as models of other planets have changed substantially after exploration by space probes, so should we be prepared for radical alterations of thought about these bodies once Pioneer 11 arrives there in 1979. Two more spacecraft, Voyager 1 and 2, are scheduled to reach Saturn in 1980 and 1981 respectively.

6. Uranus and Neptune.—The seventh and eighth planets in our solar system remain mysterious, since their distance from the Sun makes them even more difficult to observe than the planets already discussed. They do not receive, and therefore do not reflect, a great deal of of sunlight, hampering telescopic observations. The two planets are thought to be very similar to each other, so can be discussed together.

The planets were discovered in 1771 and 1846 respectively. Neptune's existence was, in fact, predicted several years prior to its actual "discovery" based on studies of the motion of Uranus. Perturbations in that planet's orbit led astronomers to believe that another body was exerting gravitational force on it; that body turned out to be Neptune.

Uranus and Neptune are thought to have the rocky cores common to the outer planets, about 16,000 kilometers in diameter with temperatures about two to three thousand degrees Kelvin. Surrounding the core is an 8,000 kilometer layer of water and methane ice, and a deep atmosphere, according to current models. These atmospheres have been spectroscopically observed to contain methane, hydrogen, and helium. As in the case of Saturn, ammonia is thought to exist in a solid layer further down in the cloud layers, and undetectable from Earth. It has not been possible so far to make measurements of the heat radiated by either of these two planets, so it is unknown whether they have internal heat sources similar to Jupiter and Saturn.

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[7] Donald M. Hunten. The Outer Planet. Scientific American, v. 233, September 1975: 140.

In 1977 astronomers discovered that Uranus has a set of rings similar to Saturn's, only five or six in number rather than four. That such a distinguishing feature should only be discovered at this late date demonstrates the difficulty in observing these planets; no similar feature has yet been detected for Neptune. Like Venus, Uranus rotates in a direction opposite to that of the majority of planets, and therefore it is called a "retrograde" rotation. Uranus also has the distinguishing characteristic of being inclined 82° to its orbit (compared to Earth's 23½° inclination), so that when observing it from Earth, one is almost looking straight at its poles, rather than near its equator.

The extremely cold temperatures on Uranus and Neptune would seem to make the possibility of life development very small. The five moons of Uranus and the two which orbit Neptune have not been observed to have atmospheres, so are not good candidates for life either.

C. Summary

The journey through our solar system ends with the conclusion that the best chance for life, other than on Earth, is on Mars, Jupiter and Titan. It cannot, however, be ruled out on *any* of the bodies, especially those with atmospheres. The reader should note, though, that in all cases we are discussing simple organic life (for example, amino acids), not intelligent life capable of building cities or spaceships. Any search for the latter type of life would have to be expanded to other parts of the galaxy.

CHAPTER TWO

THE UNIVERSAL SEARCH: POSSIBILITIES AND PROPOSALS

Prior to discussing recently advanced theories concerning the scientific possibility of other intelligent life in the universe, mention should be made that the scientists below base their calculations on the assumption that intelligent civilizations will exist on planets orbiting distant suns. There are other scenarios, however, such as Harlow Shapley's theory of planets which float freely in space without need of a sun, or even more exotic concepts such as Fred Hoyle's *Black Cloud.* The Cloud (fondly referred to as Joe), is an intelligent being which travels around the universe from star to star, and as the following dialog indicates, is surprised to find intelligent life on a planet:

> "Your first transmission [to the cloud from Earth scientists] came as a surprise, for it is most unusual to find animals with technical skills inhabiting planets, which are in the nature of extreme outposts of life."
>
> Joe was asked why this should be so.
>
> "For two quite simple reasons. Living on the surface of a solid body you are exposed to strong gravitational force. This greatly limits the size to which your animals can grow and hence limits the scope of your neurological activity. It forces you to possess muscular structures to promote movement, and it also forces you to carry protective armour against sharp blows—as for instance your skulls are a necessary protection for your brain. * * * By and large, one only expects intelligence to exist in a diffuse gaseous medium, not on planets at all.
>
> "The second unfavorable factor is your extreme lack of basic chemical foods. For the building of chemical foods on a large scale, sunlight is necessary. Your planet, however, absorbs only a very minute fraction of light from the Sun. At the moment I myself am building basic chemicals at about 10,000,000,000 times the rate at which building is occurring on the whole entire surface of your planet.
>
> "This shortage of food chemicals leads to a tooth and claw existence in which it is difficult for the first glimmerings of intellect to gain a foothold in competition with bone and muscle. Of course once intelligence becomes fairly established, competition with sheer bone and muscle becomes easy, but the first steps along the road are excessively difficult—so much so that your own case is a rarity among planetary life forms." [1]

[1] Fred Hoyle, The Black Cloud, New York, Signet Books, 1957, pp. 149–150.

Bear in mind, then, that the following discussion applies to planetary life forms only.

A. The Order of the Dolphin

The first meeting in modern times to discuss the possibility of extraterrestrial intelligence was held by the National Academy of Sciences in November 1961 at Green Bank, West Virginia. Since the august gathering included a scientist who specialized in the language of dolphins, an intelligent being on this planet with whom man has had little success in communicating, the group christened itself the Order of the Dolphin. Eleven prominent scientists met without public announcement, although the meeting was not secret, to discuss extraterrestrial intelligent life and interstellar communication. The eleven people were:

Dana W. Atchley, Jr., President, Microwave Associates, donor of the parametric amplifier for Project Ozma (see chapter 4) and a specialist in communication technology;

Dr. Melvin Calvin, Chemist, University of California at Berkeley, who received the Nobel Prize while attending the meeting;

Dr. Giuseppe Cocconi, Physics Professor, Cornell University, and co-author of "Searching for Interstellar Communications" (with Philip Morrison) the first scientific paper on the subject;

Dr. Frank Drake, National Radio Astronomy Observatory, Green Bank, West Virginia, head of Project Ozma;

Dr. Su-shu Huang, Astrophysicist, Goddard Space Flight Center, National Aeronautics and Space Administration, and a pioneer in determining what stars might have companion planets;

Dr. John C. Lilly, Animal Behaviorist, Communication Research Institute, the Virgin Islands, specialist in the language of dolphins;

Dr. Philip Morrison, Physicist, Cornell University, and co-author of "Searching for Interstellar Communications" (with Giuseppe Cocconi);

Dr. Bernard M. Oliver, Vice President for Research and Development, Hewlett-Packard Company, Palo Alto, California, communications expert;

J. P. T. Pearman, National Academy of Sciences, Space Science Board Secretariat;

Dr. Carl Sagan, Biologist and Astronomer, Cornell University; and

Dr. Otto Struve, Director, National Radio Astronomy Observatory, Green Bank, West Virginia.

The most significant result of the meeting was development of a formula to determine the possibility of extraterrestrial intelligence, often referred to as the "Drake Equation" after Frank Drake, its principal creator. Each variable in the equation is subject to different quantifications, however, and five years after the Green Bank meeting, Carl Sagan came to a different conclusion from that developed in 1961. The two results are compared below.

B. The Drake Equation [2]

The Drake Equation reads:

$$N = R_* f_p n_e f_l f_i f_c L$$

where N is the number of extant civilizations possessing interest and the capability for interstellar communication.

R_* is the mean rate of star formation averaged over the lifetime of the galaxy. The Green Bank (GB) group said this was the total number of stars in the galaxy divided by the lifetime of the galaxy. By their values this was

$$\frac{10^{10}}{10^{10}} \text{ or } 1$$

Sagan used 10^{11} as the total number of stars, so his value for R_* is

$$\frac{10^{11}}{10^{10}} \text{ or } 10$$

f_p is the fraction of stars with planetary systems. GB said the value of this factor would be either 0.4 or 0.5; Sagan said 1.

n_e is the mean number of planets in each planetary system with an environment favorable for the origin of life. Feeling that our sun was unexceptional in this regard for a star of its class, GB said between 1 and 5; Sagan uses 1.

f_l is the fraction of suitable planets on which life does develop. Agreeing that life on such planets would be inevitable, both use the value of unity, 1.

f_i is the fraction of life-bearing planets on which intelligence, accompanied with manipulative ability, appears. Here the issue of the dolphins arises, for although they are considered by many to be intelligent beings, they have no manipulative ability, and therefore do not fit into this equation. Using the same arguments to deduce their answers, GB and Sagan come to different conclusions: the former uses 1 and the latter 10^{-1}.

f_c is the fraction of planets on which an advanced technical civilization evolves. Both GB and Sagan adopt a 10^{-1} value for this factor.

L is the lifetime of the technical civilization and the most difficult variable to determine.[3] (The L period for Earth just recently began with the development of radio telescopes, since only then did we become capable of communicating with other civilizations in space, i.e., a "technical" civilization.)

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[2] Information for this section was synthesized from three sources: Walter Sullivan, We Are Not Alone, New York, McGraw Hill, 1964, pp. 250–254; I. S. Shklovski and C. Sagan, Intelligent Life in the Universe, San Francisco, Holden-Day, 1966, pp. 410–413; Tom Allen, The Quest, Philadelphia, Chilton Books, 1965, pp. 32–36.

[3] Sebastian von Hoerner has defined five different possibilities for L: (1) total obliteration of all life on the planet; (2) destruction of only the higher forms of life (leading to the possibility of regeneration); (3) physical or intellectual degeneration and decay; (4) the loss of interest in science and technology; and (5) no limitation at all (which he believes impossible). His value for L is 6,500 years. See Shklovskii and Sagan, p. 414.

At Green Bank, the group considered the two extremes of a civilization destroying itself in less than 1,000 years, or overcoming its crises and lasting almost indefinitely, or more than 100 million years. For the Green Bank group, then, the lower limit of N would be:

$$1\times.4\times1\times1\times1\times.1\times1000=40$$

The upper limit would be:

$$1\times.5\times5\times1\times1\times.2\times100{,}000{,}000=50{,}000{,}000$$

Sagan chose the extremes of L as less than 100 or greater than 10^8, assuming an average of 10^7. His lower limit for N is therefore:

$$10\times1\times1\times1\times.1\times.1\times100=10$$

His upper limit is:

$$10\times1\times1\times1\times.1\times.1\times10{,}000{,}000=1{,}000{,}000$$

The conclusion from these two calculations is that there are between 10 and 50,000,000 extant civilizations capable of communicating with us. Most estimates place the figure at one million. Stephen Dole, however, in a 1964 study for the Rand Corporation, used a different method of computation for determining the number of possible planets inhabitable by man (that is, planets on which man could exist without terraforming or material support from other planets) and concluded there are 600 million such planets.[4]

As is readily seen, determining the number of neighbors we have is a highly speculative and subjective process, with numerous contingencies.

C. International Interest

The United States is not the only country interested in finding other intelligent civilizations in the universe. The Soviet Union has had a continuing interest in the subject since the early 1960's, and in addition to holding a national meeting to discuss the problem in 1964, hosted the first international SETI meeting in 1972 at the Byurakan Astrophysical Observatory in Yerevan, U.S.S.R.[5]

Fifty four scientists from the United States, Soviet Union, United Kingdom, Hungary and Czechoslovakia met from September 5–11, 1972 to scrutinize each variable in the Drake equation, although they did not make an independent calculation for N. Many lively discussions ensued, not only on the value of each variable, but the number of variables itself. Dr. W. H. McNeill of the University of Chicago felt, for example, that there should be a separate "f" factor for each step in the evolution of civilization: from vegetable to animal, from hunter to intelligence, etc. If each of these "f's" had a value less than 1, as they were multiplied out the number of probable civilizations would decrease.[6]

In their conclusions, the group recommended the following possible research directions:

1. A search for signals and for evidence of astroengineering activities in the radiation of a few hundred chosen nearby stars

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[4] Stephen Dole, Habitable Planets for Man, Santa Monica, Calif., Rand Corporation, 1964.

[5] The proceedings of this conference were edited by Carl Sagan and published as Communication with Extraterrestrial Intelligence, Cambridge, Mass., MIT Press, 1973. Note that at the time of this meeting the acronym CETI was still in use by U.S. scientists.

[6] Carl Sagan, Communication with Extraterrestrial Intelligence, Cambridge, Mass., MIT Press, 1973, p. 116.

and of a limited number of other selected objects, covering the wavelength range from visible to decimeter waves, using the largest existing astronomical instruments.

2. A search for signals from powerful sources within galaxies of the local group, including searches for strong impulsive signals.

3. Exploration of the region of minimum noise in the submillimeter band, in order to determine its suitability for observing extraterrestrial civilizations.

The following studies are desirable:

4. The design, among others, of powerful new astronomical instruments with roughly the following parameters:

(*a*) A decimeter wave radio telescope with effective area >1 square kilometer.

(*b*) A millimeter wave telescope with effective area $>10^4$ square meters.

(*c*) A submillimeter wave telescope with effective area $>10^3$ square meters.

(*d*) An infrared telescope with effective area $>10^2$ square meters.

All of the instruments described above have the capability of providing important data on subjects quite separate from CETI.

5. The definition of a system for keeping the entire sky under constant surveillance, which could lead to a search of wider scope than those listed under 1 and 2.[7]

The Soviet Union has a significant national program to seek out other civilizations in the universe, which is discussed in section E of this chapter. Until recently it appeared that the United States and Soviet Union were the only nations with substantial interest in the field, although in 1977 the Japanese demonstrated their intent to become active in SETI by responding to a "question" introduced by the United States to a committee (the CCIR) of the International Telecommunications Union. The question related to proposed search systems for SETI and how to deal with radio frequency interference problems (see pages 49 and 58 f.f.).

D. NASA Involvement

In 1974 the National Aeronautics and Space Administration established an Interstellar Communication Study Group at Ames Research Center, Moffett Field, California. Under the leadership of Dr. John Billingham, the group arranged a series of six science workshops, chaired by Dr. Philip Morrison of MIT, with responsibility to: "examine systematically the validity of the fundamental criteria and axioms associated with a program to detect extraterrestrial intelligent life; to identify areas of research in the astronomical sciences, and in other fields, that would improve the confidence levels of current probability estimates relevant to SETI; to enumerate the reasons for undertaking a search, the values and risks of success, and the consequences of failure; to explore alternative methods of conducting a search; to select, in a systematic way, preferred approaches; to indicate the conceptual design of a minimum useful system as required to implement the

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[7] Ibid., pp. 355–356.

preferred approaches; to delineate the new opportunities for astronomical research provided by the system and their implications for system design; to outline the scale and timing of the search and the resources required to carry it out; to examine the impact of conducting a search, and the impact of success or failure in terms of national, international, social and environmental considerations; and to recommend a course of action, including specific near-term activities." [8]

The members of the Science Workshop were:

Philip Morrison, Chairman	Massachusetts Institute of Technology.
Ronald Bracewell	Stanford University.
Harrison Brown	California Institute of Technology.
A.G.W. Cameron	Harvard University.
Frank Drake	Cornell University.
Jesse Greenstein	California Institute of Technology.
Fred Haddock	University of Michigan.
George Herbig	University of California, Santa Cruz.
Arthur Kantrowitz	AVCO Everett Research Laboratory.
Kenneth Kellerman	National Radio Astronomy Observatory, Green Bank.
Joshua Lederberg	Stanford University.
John Lewis	Massachusetts Institute of Technology.
Bruce Murray	Jet Propulsion Laboratory.
Bernard Oliver	Hewlett-Packard.
Carl Sagan	Cornell University.
Charles Townes	University of California, Berkeley.

The four principal conclusions reached by the workshop are printed in full as Appendix A; in brief they are: (1) It is timely and feasible to begin a serious search for extraterrestrial intelligence; (2) a significant SETI program with substantial potential secondary benefits can be undertaken with only modest resources; (3) large systems of great capability can be built if needed; and (4) SETI is instrinsically an international endeavor in which the United States can take a lead.

Two other conferences were held as adjuncts to the Science Workshop, the first on cultural evolution in the context of SETI, chaired by Dr. Joshua Lederberg of Stanford University, and the second a set of two meetings on extrasolar planetary detection, chaired by Dr. Jesse Greenstein of the California Institute of Technology.

In 1976, the Jet Propulsion Laboratory in Pasadena, California, which has responsibility for NASA's planetary programs, set up a SETI program office to work in concert with the Ames group. The primary difference between the efforts of the two institutions is that the JPL group is interested in performing sky surveys of thousands of stars, while the group at Ames is more concerned with studying a few, selected stars. The former alternative would allow a small amount of time to be spent studying a large number of stars with comparatively low sensitivity, while the latter would permit a more detailed study of a smaller number of stars with higher sensitivity. The two groups propose that the optimal approach would be to perform

[8] NASA. SETI: Search for Extraterrestrial Intelligence. NASA SP 419 [prepublication American scientists who have substituted SETI (see p. 47).

both types of studies and pool the results. The Science Workshop recommended the Ames-type of search, possibly complemented by the sky survey type.

The Ames SETI program office has also funded SETI-related projects, such as radio searches by Ohio State University, and efforts to detect planetary companions by George Gatewood of Allegheny Observatory. Since fiscal year 1975, NASA has expended $850,000 on SETI.

E. The Soviet Program

The Soviet Union has had a long standing interest in finding other intelligent life in the universe, and has performed searches with radio telescopes of the Shternberg Astronomical Institute. In 1965, Prof. Iosif Shklovskii, who is best known in the West as co-author of *Intelligent Life in the Universe* with Carl Sagan in 1966, reported that unusual radio signals had been detected from the astronomical object CTA–102.[9] At the time the signals were discovered, scientists would not state whether the radio signals, which had been observed since August 1964, were of natural or artificial origin. Prof. Nikolai Karadashev was cited as favoring the artificial origin thesis.[10] Since that time, CTA–102 has been identified as a quasar, which accounts for the radio signal pattern received by the Russian astronomers.

The Soviet Union held a meeting to discuss other life in the universe in 1964, although details of the meeting are scarce in the West. As noted previously, Russians hosted the first international meeting on the subject in September 1972. Both meetings were held at the Byurakan Astrophysical Observatory in Armenia.

In March 1974, the Board of the Science Council of the Radio Astronomy Problem Area of the USSR Academy of Sciences approved a research program for communication with extraterrestrial intelligence, designated CETI.[11] The full text of the program, which covers the time period 1975 through 1990, is printed as Appendix B; its basic principles are:

1. Efforts to detect extraterrestrial civilizations should proceed smoothly and systematically, and should extend over a prolonged period of time. The program is oriented in this direction from the very outset. It would be a great mistake to build a program in contemplation of rapid and easy success.

2. Investigations should be based on a specifically devised program (or group of programs) which would be revised and perfected as time passes. The program should provide every opportunity to take advantage of existing technology (radio telescopes, antenna systems and associated instrumentation), and should also envision the development of specialized techniques and equipment for coping with the CETI problems.

3. The program will recognize that astrophysical information will be acquired as a byproduct of the search for signals from extraterrestrial civilizations. When actual investigations are undertaken it will be necessary to analyze carefully the question of

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[9] TASS, Apr. 13, 1965, 1518 GMT.
[10] TASS, Apr. 14, 1965, 0730 GMT.
[11] As noted previously, the Russians continue to use the acronym CETI, as opposed the American scientists who have substituted SETI (see p. 47).

what astrophysical applications can be pursued during search activities.

4. In view of the uncertainty in our prior knowledge as to the character of signals from extraterrestrial civilizations, the program should entail parallel studies in several directions.

The Soviet plan is very ambitious, with proposals to search the entire shortwave segment of the spectrum—from 1 to 100 gigahertz. The plan would proceed in two overlapping phases. The first, CETI 1, would run from 1975 to 1985 and involve an all sky survey using eight ground stations supplemented by observations from two earth orbiting satellites. CETI 2, from 1980 to 1990, would see enlargement of the satellite antennas, as well as inclusion of two radio telescopes with one square kilometer collecting areas. The outstanding difference between the U.S. and Soviet programs is use of satellite antennas. Although the U.S. plan recognizes the possible necessity of placing antennas either in earth orbit or on the Moon should radio frequency interference on the surface of Earth become overwhelming, it does not specifically suggest using satellites to augment research performed from the surface. That is, space antennas are viewed as an alternative to earth based arrays, rather than as a supplement.

The Soviet searches are continuing, and now also make use of the new RATAN 600 radio telescope in Northern Caucasus. Dr. Karadashev is currently directing these efforts, and seems particularly interested in studying point sources of shortwave emissions from the center of the galaxy.[12]

An interesting development in the pursuit of CETI in the Soviet Union was the apparent change of opinion by Prof. Shklovskii concerning the probability of other life in the universe. In 1976, Shklovskii authored an article entitled "Possible Uniqueness of Rational Life in the Universe" in the Russian journal, *Voprosy Filosofi*.[13] The noted scientist did not completely retract his previous thesis that life was very probably common in the universe, but rather presented philosophical arguments that the idea of the universe being widely inhabited is no more plausible than that of Earth's inhabitants being unique. Prof. Shklovskii concluded that "it appears to us that the conclusion that we are alone, if not in the whole universe, then in any case in our Galaxy or even in the local galaxy system today is no *less* well supported, and much better, than the traditional concept of the multiplicity of inhabited worlds. * * * even from the now widespread 'optimistic' ideas that the closest extraterrestrial civilizations are 200–300 parsec from us, we must view ourselves as being *virtually alone*. For in the region of our Galaxy with a 300 parsec radius there are about 10 million stars, graphically demonstrating the rarity of the phenomenon of rational life in the universe." [14]

Although his statements do not preclude the possibility of other intelligent life in the universe, such a significant change of position by a renowned scientist in the field could serve to reduce the credibility of CETI in the Soviet Union. To date, however, the 1974 proposal appears to remain in effect.

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[12] CETI in the Soviet Union. Spaceflight, v. 19, May 1977: 193–196.

[13] I. S. Shklovskii. Possible Uniqueness of Rational Life in the Universe; Voprosy Filosofi. No. 9. 1976, pp. 80–93. NASA Technical Translation TT F–17, 404, February 1977, Washington, D.C., National Aeronautics and Space Administration, 1977.

[14] Ibid., p. 24. Emphasis Shklovskii's.

CHAPTER THREE

WHERE TO LOOK

Knowing the statistical probability that other intelligent civilizations exist is only the beginning; the next question is where to look for them. With over 10^{11} stars in the galaxy (and 10^{22} in the known universe), where should the search begin?

A. Finding Us

As an exercise in assessing the difficulty inherent in searching for other life-bearing worlds, one could examine the case of how difficult it would be for another civilization to find us.

In a 1966 German magazine, an article entitled "Is Life Possible on the Surface of Earth"[1] appeared in which the author fancied himself a scientist on Jupiter examining the possibility of other life in the solar system. Since Jupiter was then considered to be extremely cold, with oceans filled with ammonia and an atmosphere composed primarily of methane,[2] the Jovian scientist could only conclude that life "as he knew it" could not exist on a planet as hot as Earth, with no methane in the atmosphere and no liquid ammonia on the surface of the planet.

David C. Holmes, in *Search for Life on Other Worlds*, points out that a Martian scientist would also have a hard time detecting life on Earth, even with optical telescopes as powerful as ones we presently have available:

> Our greatest engineering structures would be too insignificant to be seen, or perhaps would be barely on the threshold of visibility. In this they would appear similar to the way the celebrated Martian canals appear to us.
>
> The lights of New York and London might be marginally visible at night. About the only man-made phenomenon easily seen by Martian astronomers would be nuclear explosions. And these are over so quickly that many would never be seen. Those that were would be the focal point of many arguments among astronomers.
>
> An astronomer on Mars might notice seasonal color changes in our planet like those we have observed on the red planet itself. No doubt the Martian scientists would devise many ingenious theories to explain these phenomena, just as we have. A good many of them would surely exclude the possibility of life.[3]

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[1] As referenced in Capt. David C. Holmes, Search for Life on Other Worlds, New York, Sterling Publishing Co., 1966, p. 5.

[2] Data from Pioneer 10 and 11 have shown Jupiter to be quite different than what was accepted as fact in 1966. See Chapter 1.

[3] Holmes, op. cit., pp. 7 and 8.

From further out in space, the solar system would appear merely as four planets (Jupiter, Saturn, Uranus and Neptune) and debris.[4] How would anyone even suspect that a civilization with at least some technical capability exists on one of those inner pieces of rock?

In his study for the Rand Corporation, Stephen Dole shows where our sun would appear in the sky to an observer on our nearest neighbor, Alpha Centauri. We would simply be another star in the constellation Cassiopeia.[5]

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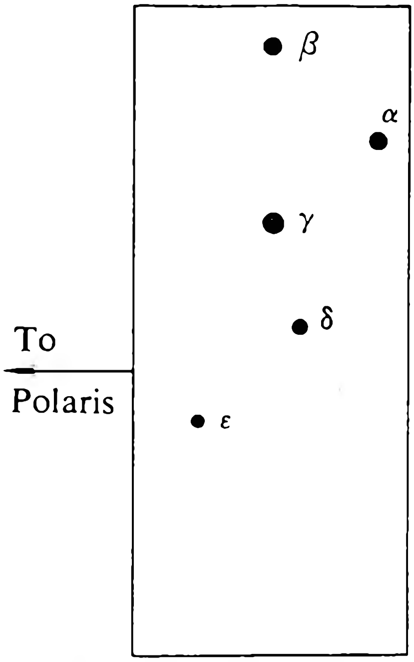
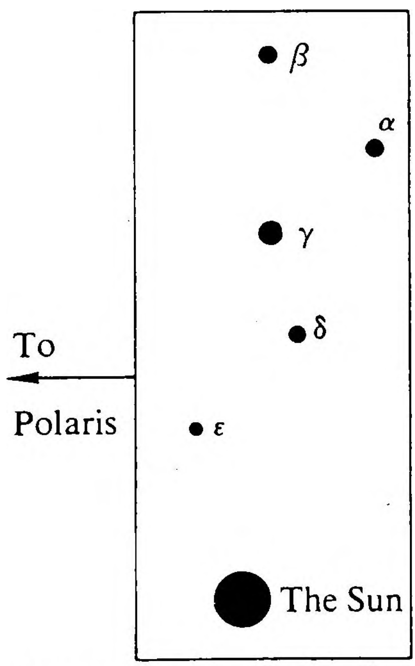
[4] I. Shklovskii and C. Sagan, Intelligent Life in the Universe, San Francisco, Holden-Day, 1966, p. 215.

[5] Stephen Dole, Habitable Planets for Man, Santa Monica, Calif., the Rand Corporation, 1964.



As seen from the Earth



As seen from α Centauri

The principal stars in Cassiopeia. Source: Stephen Dole. Habitable Planets for Man. Santa Monica, California, the RAND Corporation, 1964.

B. Finding Them

1. *Suitable star systems*

Su-shu Huang, an astrophysicist presently with Northwestern University, was a pioneer in the field of suggesting where to look for habitable planets. His first concern was determining the age a star would have to be in order for life to develop on any planets it might have.[6]

> Biological evolution results from mutation—a random process—and is therefore slow. In the case of our experience on the Earth, its time scale is on the order of [one billion] years. If we accept this as an average value for biological evolution in general, we find that the time scale of evolution for main sequence stars of early spectral types (O, B, A and perhaps early F) is too short for developing an advanced form of life on their planets even if the latter exist.

Huang's next concern is the "habitable zone" surrounding stars which would provide a correct temperature on a planet for the development of life, and finds that this zone increases with the star's luminosity and thus becomes smaller and smaller as one goes down the main sequence. He therefore concludes that M or late K stars would be unlikely to support life. Others disagree, however, noting the difficulties inherent in assessing what a "correct" temperature is for non-human life forms. In addition, planets could conceivably have internal heat sources thereby obviating the necessity of being located near a sun. Under the Huang scenario, though, only F, G, and early K stars would be likely candidates (our sun is a type G star).

In contemplating the question of where to find habitable planets, the issue of binary stars arises, especially since recent evidence seems to indicate that a majority of stars are members of multiple star systems. It is possible that as a gas cloud condenses to form stars, it separates into two or more distinct masses. The additional mass could form companion stars or planets. Abt and Levy, in a study of 136 F_3 to G_2 stars found that two-thirds of the stars had detectable stellar companions. They theorized that most of the remaining third probably had companions too small or too close to the primary for detection from Earth. They then concluded that "almost all systems are either double, triple, or greater. Therefore the solar system, in not having a stellar companion, is a rare type of system."[7]

For those stars that do not have detectable stellar companions, planetary companions are an alternate possibility. The probability of life developing on any such planets in a binary system relates back to Huang's argument for the necessity of stable environmental factors. In a binary system, a planet would travel in an erratic orbit, sometimes close to both stars, other times far away. This could create appreciable changes in environmental conditions, possibly precluding development of life. Conditions for life would probably be best in a system of close binaries where a planet might use both stars as an orbital center and therefore travel in a more regular orbit. Harvard

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[6] Su-Shu Huang. Problem of Life in the Universe and the Mode of Star Formation. *In* A. G. W. Cameron. Interstellar Communication. New York. Benjamin. Inc.. 1963. pp. 89–92.

[7] Helmut A. Abt. and Saul G. Levy. The Binary Frequency Among Solar-Type Stars. American Astronomical Society Bulletin. v. 7. 1975 : 268.

astronomer A. G. W. Cameron has concluded that "In general, most binary systems, and all binary systems with large separations between the components, can be regarded as unlikely locations for life-bearing planets." [8]

The next factor to take into account in finding suitable planets for life development is what mass a planet should have. It must be large enough to retain an atmosphere at its distance from the sun, but small enough to let most of its hydrogen escape so it does not use up all the oxygen by combining with it to form water. Huang calculated that the planet's radius should be between one thousand and twenty thousand kilometers.[9]

Yet another consideration is the radiation level on the planet, which would have to remain constant for billions of years. All the stars on the main sequence fulfill this qualification, although variable stars do not.[10] Walter Sullivan presents a summary table of conditions necessary for the evolution of life on a planet (figure 3-2).

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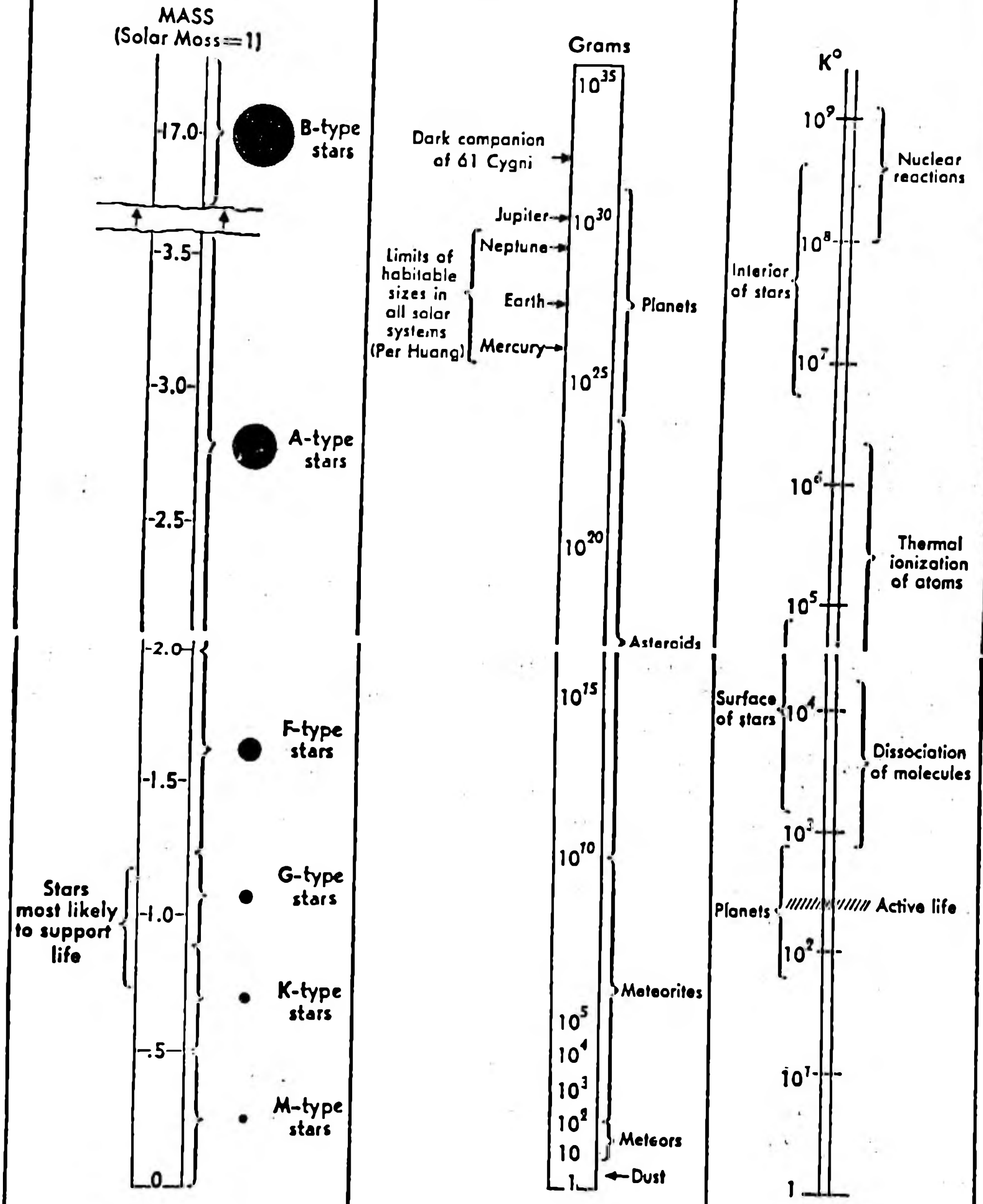
[8] Cyril Ponnamperuma and A. G. W. Cameron, Interstellar Communication: Scientific Perspectives, Boston, Houghton, Mifflin, 1974, p. 268.
[9] Walter Sullivan, We Are Not Alone, New York, McGraw Hill, 1966, p. 63.
[10] Shklovskii and Sagan, op. cit., p. 347.

THREE REQUIREMENTS FOR LIFE

STAR SIZE
A sun of proper warmth and longevity.

PLANET SIZE
A planet massive enough to retain an oxygen atmosphere and small enough to allow its hydrogen to escape.

TEMPERATURE
A temperature at which water is liquid.



Star sizes are given in terms of solar masses, one solar mass being equal to the mass of the sun. Only visible stars on the "main sequence" are shown, thus excluding far larger stars, such as the "red giants."

Planet masses are given in grams, one gram being roughly .03 ounce. The scale is logarithmic in powers of 10. For example 10^{10} represents 10 multiplied by itself 10 times, which is the numeral 1 followed by 10 zeros (ten billion).

Temperatures are in the "absolute" or Kelvin scale. That is, the spacing between degrees is similar to that in the centigrade scale, but zero is equal to "absolute zero," the total absence of heat. On the absolute scale, water freezes at 273.16° and boils at 373.16°. As with planet size, the scale is in powers of 10.

Source: Walter Sullivan. We Are Not Alone. New York, McGraw Hill, 1966: 64-65. Reprinted with permission, copyright 1964, 1966 by Walter Sullivan.

2. Planetary detection

Assuming planets do exist around distant stars, how could they be detected from Earth? At the vast distances involved, "seeing" a planet is extremely difficult. The method currently in use involves the study of perturbations in the orbit of a star and is called astrometry (see below). It is far from infallible, and over the years astronomers have "discovered" several planetary companions, only to have other astronomers find flaws in the data itself or in the interpretation of the data. There is currently no unambiguous data to support the conclusion that any other star has planetary companions, although five are often cited as being good possibilities.

George Gatewood, Director of the Allegheny Observatory, has published his assessment of the likelihood of finding such companions.

FIG. 3-3.—SUSPECTED PLANETARY SYSTEMS

Name of system	Distance (light years)	Planet mass [1]	Remarks
Barnard's Star	5.9	1.1 and 0.8	Doubtful.
Lalande 21185	8.2	10	Doubtful.
Epsilon Eridani	10.8	6 to 50	Doubtful.
61 Cygni	11.0	8	Doubtful.
BD-43° 4305	16.9	10 to 30	Needs study.

[1] Planet mass in Jupiters.

Source: George Gatewood. On the Astrometric Detection of Neighboring Planetary Systems. Icarus, January 1976: 2. Updated by Dr. Gatewood Nov. 1977.

a. Astrometry.—Just as the Moon orbits the Earth and the Earth orbits our Sun, the Sun and other stars orbit the center of the Milky Way galaxy. One method of determining whether a star is alone or has a companion (either stellar or planetary) is by studying the path of its orbit around the galaxy. Normally, the orbit will be virtually a straight line, but if a companion of great enough mass is present, it will gravitationally pull on the visible star and cause it to deviate from that line; the measurement of these motions is called astrometry. By knowing how much the orbit deviates, a calculation can be made to determine the mass of the companion(s). In the case of our solar system, Jupiter causes our Sun to "wobble" in its orbit and another civilization could detect its presence by astrometry (actually, several superimposed wobbles would be noted by another civilization, since Saturn, Uranus, and Neptune would also have a gravitational effect.)

George Gatewood has derived a "planetary detection index" to calculate how massive a planet would have to be in order to be detected around certain stars:

$$I=\frac{A}{mP^{2/3}}=\frac{\pi}{M^{2/3}}$$

where A is the semimajor axis of the star, m is the mass of the companion, M is the mass of the star, and P is the period.

Using this formula he has calculated the index for 36 stars within 16 light years of our Sun. In general, a star with an index of 0.9 would reveal a Jupiter-size companion to an astrometrist using current instrumentation and the higher the index, the better the chances of discovery.

FIGURE 3-4

PLANET DETECTION INDEX FOR STARS IN THE VICINITY OF THE SUN

Star Name	Distance (light years)	Star mass (in suns)	Detection Index
1. Proxima Cen	4.3	0.11	3.3
2. Barnard's Star	5.9	.15	1.9
3. Wolf 359	7.6	.10	2.0
4. Lal 21185	8.2	.29	.9
5. Ross 154	9.5	.15	1.2
6. Ross 248	10.3	.13	1.2
7. Luy 789-6	10.7	.15	1.1
8. Epsilon Eridani	10.8	.76	.4
9. Ross 128	10.8	.15	1.1
10. 61 Cygni A	11.0	.58	.4
11. 61 Cygni B	11.0	.46	.5
12. Epsilon Indi	11.2	.63	.4
13. Sigma 2398 A	11.5	.25	.7
14. Sigma 2398 B	11.5	.21	.8
15. Grb 34 A	11.6	.29	.6
16. Grb 34 B	11.6	.15	1.0
17. Lac 9352	11.7	.37	.5
18. Tau Ceti	11.8	.81	.3
19. G51-15	12.0	.09	1.3
20. BD-5 1668	12.1	.23	.7
21. Luy 725-32	12.5	.15	.9
22. Lac 8760	12.5	.45	.4
23. Kapteyn's S	12.7	.27	.6
24. Kruger 60 A	12.9	.20	.7
25. Kruger 60 B	12.9	.13	1.0
26. BD-12 4523	13.1	.22	.7
27. Van Maanen's	14.2	.7	.3
28. CD-37 15492	14.5	.32	.5
29. G158-27	14.6	.10	1.0
30. Grb 1618	14.7	.51	.4
31. CD-46 11540	15.1	.26	.5
32. G208 44	15.2	.12	.9
33. G208 45	15.2	.11	.9
34. CD-49 13515	15.2	.31	.5
35. CD-44 11909	15.3	.18	.7
36. Luy 1159-16	15.3	.14	.8

Source: George Gatewood. On the Astrometric Detection of Neighboring Planetary Systems. Icarus, Jan. 1976, p. 7.

In addition, Dr. Gatewood has chosen 33 stars which he is specifically interested in studying.

FIGURE 3-5

Name	Mass	Detection Index
1. G 158-27	0.10	1.0
2. Grommbridge 34A	.29	.6
3. Groombridge 34B	.15	1.0
4. Van Maanen's Star	.7 2/	.3
5. L 725-32	.15	.9
6. Tau Ceti	.81	.3
7. L 1159-16	.14	.8
8. Epsilon Eridani	.76	.4
9. Stein 2051 A	.18	.6
10. Stein 2051 B	.5 3/	.3
11. Ross 47	.18	.5
12. BD 5 1668	.23	.7
13. G 51-15	.09	1.3
14. Groombridge 1618	.51	.4
15. Wolf 359	.10	2.0
16. Lalande 21185	.29	.9
17. Ross 128	.15	1.1
18. Lalande 25372	.33	.4
19. LFT 1120	.19	.5
20. BD-12 4523	.22	.7
21. AOe 173642	.28	.5
22. Barnard's Star	.15	1.9
23. Sigma 2398 A	.25	.7
24. Sigma 2398 B	.21	.8
25. Ross 154	.15	1.2
26. G 208-44	.12	.9
27. G 208-45	.11	.9
28. 61 Cygni A	.58	.4
29. 61 Cygni B	.46	.5
30. Kruger 60 A	.20	.7
31. Kruger 60 B	.13	1.0
32. L 789-6	.15	1.1
33. Ross 248	.13	1.2

1/ George Gatewood. Proposal to Survey Nearby Stars for the Perturbative Extrasolar Planetary Systems. Submitted to the National Aeornautics and Space Administration, July 9, 1975: 17-18.

2/ Mass determined from gravitational redshift.

3/ Estimated mass.

As mentioned above, astrometry is prone to errors of various natures: human (primarily in the interpretation of data), systematic (problems with the telescope system itself), and random. In the summer of 1976, a study was performed by NASA Ames Research Center in conjunction with Stanford University to determine what could be done to reduce astrometric errors.

Two proposals concerning astrometric telescopes were forthcoming from the summer study. The first involves modifying existing astrometric telescopes (refractors) to reduce random error to the maximum extent possible. This would involve using a device designated MAP, for multichannel astrometric photometer, in place of the photographic process now in use for recording the images of the stars. Dr. Gatewood has cited the photographic process as "the major source of random observational error"[11] and thinks MAP-equipped telescopes could increase precision by a factor of three. It would cost about $300,000 to equip an existing telescope with a MAP device.

The second proposal calls for constructing special astrometric telescopes for reducing systematic errors. One problem with refractors is that as the telescope moves to follow the target star or is repaired, the lens can shift slightly. The resulting star image on the photographic plate registers the change in position of the star caused by the shift of the lens, and produces the same type of reading one would obtain if the target star had an unseen companion. Therefore, if a telescope could be designed which would eliminate the necessity of moving the lens, one problem area would be averted.

With regard to this possibility, a "10 parsec survey instrument" was designed which would maintain the lens in a stationary position (see figure 3–6). The only part of the system that would move would be the siderostat's mirror, which in effect tracks the target star. The lens, together with the rest of the telescope's vital parts, are enclosed

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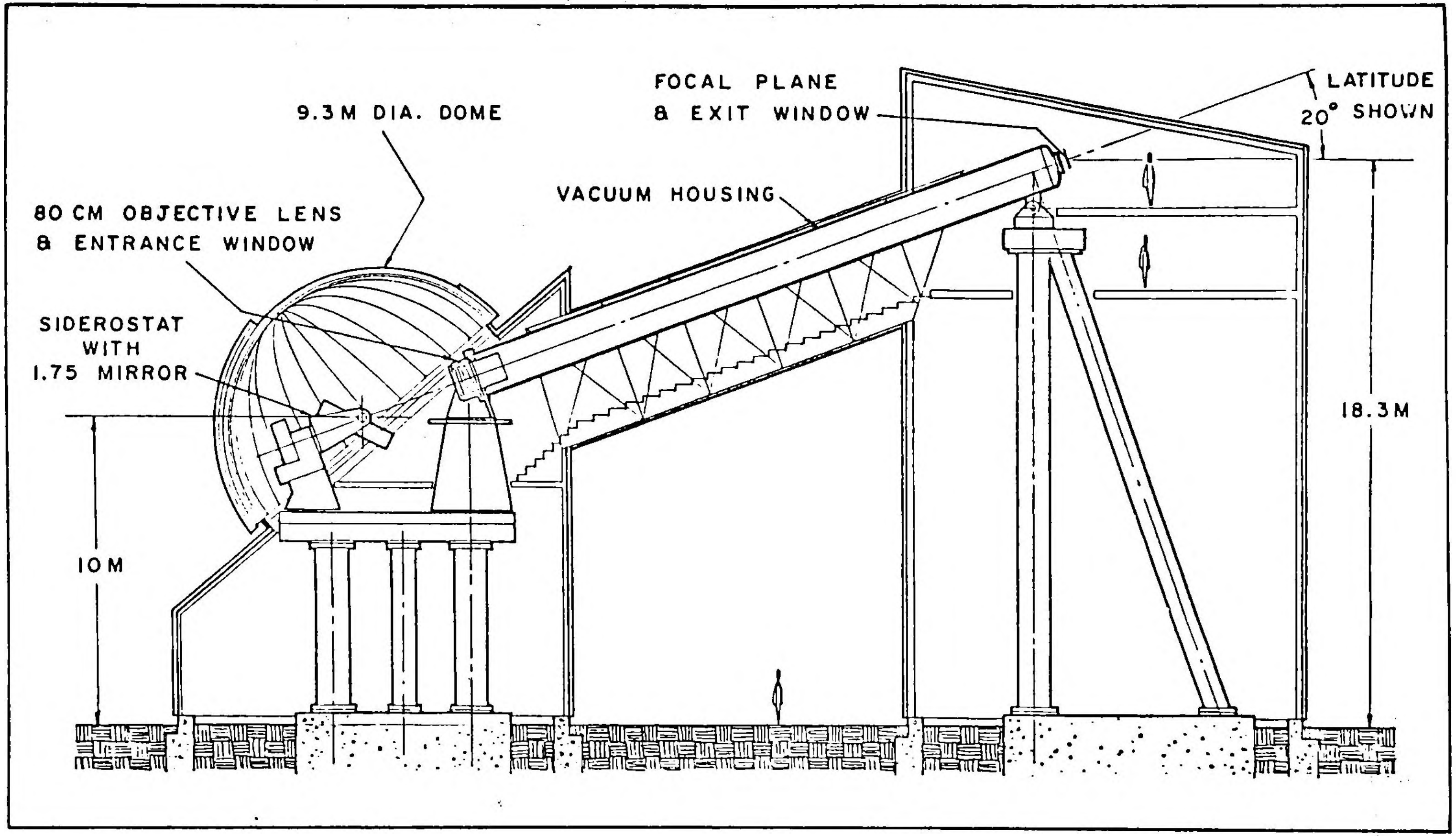
[11] George Gatewood, private correspondence.



Source: George Gatewood, Allegheny Observatory.

in a vacuum tube which maintains constant environmental conditions (such as temperature) and precludes settling of dust. It is thought that such instruments would increase the precision of current studies by 30 to 50 times using this design (the telescopes would also be equipped with MAPs). The cost of one of these systems has been appraised at $4 million.

Another possibility calls for using these telescopes in interferometer systems, that is, two telescopes separated by a specific distance (perhaps 50 meters). Each telescope views the target star and the resulting images are combined so that the rays of light either add together in phase or cancel each other out. In this way, a very sharp image of the target star is produced. It has been recommended that two interferometers (four telescopes) be constructed, one in the northern hemisphere and one in the southern hemisphere. Each interferometer would cost about $40 million. Another possibility is placing the interferometer in space or on the moon to relieve the problem of atmospheric distortion.

b. Apodization.—There are three other methods that have been proposed to discover planets. The first is by a process called apodization where one literally tries to see another planet. Supporters say that using this method one could see Jupiter from a distance of 10 parsecs.

When looking at a star through a telescope, the light from the star is diffracted around the edge of the objective (either a mirror or lens depending on what type of telescope is used). The star appears fuzzy and looks larger than it actually is, and effectively covers up any light that may be reflected by a planetary companion. Scientists hope that by using a piece of glass layered with silvering material (the same kind used on mirrors for reflecting telescope) so that it is clear in the center but becomes darker and darker as it reaches the edge, the diffraction problem will be diminished. The apodized surface would be placed somewhere in the telescope's optical path, perhaps at the aperture or over the objective itself (note that it would not be at the focal point). This would result in a precise, clear image of the target star.

As a possible second step, an occultation filter could be placed at the focal point (probably a photographic plate). As opposed to the apodized surface, the center of the occultation filter would be darkest in the center and gradually become light towards the edge. This would block out the light from the star itself and leave only the light reflected by planetary companions.

Those who doubt the efficacy of this system submit that a planet would have to be fairly close to the star to reflect enough light to be seen.

c. Radial velocity.—As mentioned earlier, all the stars in the galaxy are moving in an orbit around the center of the Milky Way. Through changes in their spectral lines (called Doppler shift), astronomers measure the rate at which stars move toward or away from our Sun, and this speed is called radial velocity.

Consider a star moving toward our Sun. If the star has a massive planetary companion in orbit parallel to our line of sight, as it comes in front of the star (from our point of view) the planet will pull on

the star and cause it to travel towards us at a faster speed. Likewise, when in back of the star, the planet will pull the star away from us and cause the star to slow down. Through studies of the resulting Doppler shift, then, astronomers may be able to determine if a companion is present.

Two problems associated with this method are: (1) the amount of change would be very small and perhaps not noticeable even with the refined techniques currently available, and (2) astronomers are not certain that radial velocity is always consistent. As the Earth moves in its orbit around the Sun, a star's radial velocity will change, since we are in different positions relative to each other. This motion is known and can be accounted for, but other factors could exist that also change radial velocity, for example, if the star emits solar flares as our Sun does. If a change were detected, there would be no definitive way to know if it was caused by a planetary companion or by processes within the star itself.

d. Eclipsing.—If planets were orbiting another star, at some point they would pass across the star's face and cause an eclipse. Some astronomers think this might reduce the visual brightness of the star to a measurable extent. In order to see this effect, however, the Earth would have to be located very near the orbital plane of the planets, and the probable infrequency of this occurring severely limits the usefulness of this technique.

CHAPTER FOUR

METHODS OF CONTACT

Now that at least a few places in which to start looking for intelligent extraterrestrial life have been identified, the next question is how to communicate with it. There are three possible methods of contact: (1) electromagnetic signals; (2) unmanned probes; and (3) manned ships. In all three cases, communication can be initiated from either civilization.

It should be noted that the NASA Interstellar Communication Study Group chose to change the acronym CETI, for Communication with Extraterrestrial Intelligence, to SETI, for Search for Extraterrestrial Intelligence. The change was made to emphasize that at this point in time, at least, their concern is with finding a signal, not responding to it. A decision on whether or not to respond would have to be made after analysis of the message's content, which could take decades. The Soviet Union still uses the CETI acronym, however, which probably is not indicative of a stronger desire to respond to any received message, but simply a difference in perception of the need to specify which approach they intend to take.

A. Receiving Electromagnetic Signals

There are three types of signals we could conceivably intercept from another civilization: local broadcasts such as television and commercial radio; calls between two extant civilizations communicating with each other; and announcement signals made for the specific purpose of attracting attention to itself, such as beacons.

There are two requirements for any such intercepted signal: it must be distinguishable from the background noise of space (remember that all matter in the universe emits radio waves encompassing all frequencies and stars radiate a great deal of light), and must be modulated or differentiated so there is no doubt as to its intelligent origin.[1]

The first problem encountered in searching for signals from other worlds has already been discussed: where to look. As Figure 4–1 shows, different investigators have chosen different targets, covering "less than 0.1 percent of the number that would have to be investigated if there were to be a reasonable statistical chance of discovering one extraterrestrial civilization." [2]

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[1] See G. V. Foster, Non-Human Artifacts in the Solar System, Spaceflight, v. 14, December 1972: 447.

[2] Carl Sagan and Frank Drake, The Search for Extraterrestrial Intelligence, Scientific American, v. 232, May 1975: 83.

FIGURE 4-1

SEARCHES TO DATE

INVESTIGATOR	OBSERVATORY*	DATE	FREQUENCY OR WAVELENGTH	TARGETS
Drake	N.R.A.O.	1960	1,420 MHz	Epsilon Eridani Tau Ceti
Troitsky	Gorky	1968	21 and 30 cm	12 nearby sun-like stars
Verschuur	N.R.A.O.	1972	1,420 MHz	10 nearby stars
Troitsky	Eurasian Net-work, Gorky	1972 to Present	16, 30 and 50 cm	Pulsed signals from entire sky
Zuckerman Palmer	N.R.A.O.	1972 to Present	1,420 MHz	600 nearby sunlike stars
Kardashev	Eurasian Net-work, I.C.R.	1972 to Present	Several	Pulsed signals from entire sky
Bridle Feldman	A.R.O.	1974 to Present	22.2 GHz	Several near-by stars
Drake Sagan	Arecibo	1975	1,420, 1,653, and 2,380 MHz	Several nearby galaxies
Dixon	O.S.U.	1973 to present	1,420 MHz	Area search

* N.R.A.O. - National Radio Astronomy Observatory, Green Bank, West Virginia.
A.R.O. - Algonquin Radio Observatory, Algonquin Park, Canada.
O.S.U. - Ohio State University

The second problem is knowing the frequency they would use in their transmissions. Philip Morrison and Guiseppe Cocconi suggested in their pioneering paper "Searching for Interstellar Communications" (first published in *Nature* in 1959) that the best frequency to try would be 1420 megahertz: "* * * on the most favored radio region there lies a unique, objective standard frequency which must be known to every observer in the universe; the outstanding radio emission line at 1420 Mc/sec * * * of neutral hydrogen." [3]

Since 1959, however, it has been discovered that the emission line of hydrogen is far from unique; many elements have emission lines located throughout the spectrum. For example, the hydroxyl radical (OH) has emission lines at 1612, 1665, 1667, and 1720 MHz. Interest has now turned to the part of the spectrum bounded by the emission lines of hydrogen and the hydroxyl radical, which is often referred to as the "waterhole" since hydrogen (H) plus the hydroxyl radical (OH) equals water (H_2O). Many exobiologists think that water is common to all life, even that which may be discovered on some far

[3] G. Cocconi and P. Morrison, Searching for Interstellar Communication. *In* A. G. W. Cameron, Interstellar Communication, New York, Benjamin, Inc., 1963, pp. 161–162. Note that Mc/sec or megacycles per second is the same as megahertz.

distant planet, so some radioastronomers consider the waterhole a natural meeting place for disparate civilizations, and the most promising area of the spectrum in which to locate extraterrestrial signals.

Other scientists do not agree. Since hydrogen is the most abundant element, the 1420 MHz frequency is very noisy, which would make signals at that wavelength somewhat more difficult to detect. Noise is a problem at many frequencies, and the Japanese have recommended that SETI searches be made at 4830 MHz (the formaldehyde emission line) because it has a low noise component. They have also suggested 1666 MHz, since it is in the middle of two OH emission lines; close enough to be reasonable contenders for interstellar messages but far enough away from the emission lines to lessen noise problems.[4] Figure 4–1 summarizes those frequencies that have already been searched.

NASA's Interstellar Communication Study Group Science Workshop group recommended pursuing the waterhole wavelengths, and fostered an attempt to have those frequencies reserved for SETI so transmissions from satellites and airplanes will not drown out interstellar messages (see section 4).[5]

Another difficulty is determining what bandwidth another civilization would use in their communications. The narrower the bandwidth, the further the signal can travel before it dissipates, but the less information the message can carry. Drake has written that "Since we are attempting * * * to intercept transmissions of great power, where great range is presumably the goal, we can expect the signals to be of narrow bandwidth."[6] "Presumably" is the key word here, since there is no way for us to know if the transmitting civilization would want to announce itself by sending a short message a long distance (as we have already done, see section B.1.a. of this chapter), or communicate extensive information about itself regardless of travel time to the nearest recipients. The latter situation could arise if a civilization knew its sun was about to turn into a supernova and wanted its culture and knowledge to survive.

1. Past and current searches

a. Project Ozma.—Despite the plethora of difficulties, Frank Drake began the first search for signals from other worlds in 1960 at the National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia. He named his project Ozma, after the process of OZ, a place far away, difficult to reach, and populated by exotic beings.

Ozma used the 1420 MHz frequency and a narrow bandwidth of 100 hertz. The receiver was aimed at two stars, Tau Ceti and Epsilon Eridani, both about 11 light years distant.

> In an effort to eliminate background interference, such as manmade emissions and natural "noise" sneaking in from other parts of the sky, two receiving "horns" were rigged at the focus of the great 85-foot dish. One horn was aimed to receive signals from the target star (and its planets, if any) re-

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[4] Radiocommunication Requirements for Systems to Search for Extraterrestrial Life. Report to the CCIR Study Group [of the International Telecommunications Union] on Question 17/2. by Japan. Doc. 2/J–4, 1977, p. 3.

[5] See : Bernard M. Oliver, Rationale for Preferred Frequency Band : The Water Hole. In NASA. SETI : Search for Extraterrestrial Intelligence, NASA Sp 419 [prepublication issuance] Moffett, Calif., NASA, 1977 : 65–74.

[6] Frank D. Drake, How Can We Detect Radio Transmissions from Distant Planetary Systems? In Cameron, op. cit., p. 170.

> flected to the focus by the parabolic dish. The other horn was aimed away from the star and did not catch the reflected radio waves, yet, like the target horn, it picked up background noise and stray emissions sneaking in from other parts of the sky. An electronic switch, operating at very high speed, alternately connected the two horns to the receiver. All emissions entering the receiver from the horn aimed away from the star were assumed to be interference and this amount of noise was subtracted, automatically, from the emissions arriving via the other horn. What remained, it was hoped, would be any signals coming from the distant solar system, plus "cosmic noise" reflected to the focus from the small region of the galaxy lying directly behind the star.
>
> Another arrangement, designed to eliminate the cosmic noise, was based on Drake's assumption that artificial signals, for maximum efficiency, would be concentrated into a band of frequencies no more than 100 cycles in width. The receiver listened simultaneously on a broad bandwidth, which was assumed to be almost entirely cosmic noise, and on a narrow bandwidth. The broad-band noise was then subtracted, electronically, from the narrow-band reception, leaving exposed the signals from life elsewhere.[7]

On April 8, 1960, the dials were set and the receiver activated. That first day Drake detected a very strong signal from the area of Epsilon Eridani which caused quite a stir in the control room, but was later discovered to be an earth-based signal apparently related to a secret military experiment.

Project Ozma did not detect signals from another civilization, but it was not a failure. During the three months of its operation, Ozma focused on only two stars out of billions, for a total observing time of 150 hours. This was only the beginning.

b. Ozma II.—In 1972, two astronomers at NRAO undertook a follow-on search to that performed by Dr. Drake, designating it Ozma II. The astronomers, Ben Zuckerman of the University of Maryland and Patrick Palmer of the University of Chicago, searched both Tau Ceti and Epsilon Eridani, as Drake had done, and also made a survey of 659 nearby stars or star-systems. Again operating at 1420 MHz they made five week-long searches between November 1972 and August 1975, for a total observing time of about 400 hours.[8] An interesting testimonial to the technological advances made in the intervening years is that the search which required Drake 150 hours of observing time could now be performed in about five minutes.[9]

Zuckerman and Palmer were also unsuccessful in locating signal from another civilization, but they did not appear discouraged. They commented that the most serious difficulty is choosing a frequency to search, and recommended that attention be placed on developing a capability to analyze large sections of the radio spectrum at one time.[10]

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[7] Walter Sullivan, We Are Not Alone, New York, McGraw-Hill, 1966, p. 202. Reprinted with permission. Copyright 1964, 1966 by Walter Sullivan.

[8] Zuckerman and Palmer also apparently made a few trips back to NRAO for follow-up studies after this main portion of their study was completed. See : Robert Sheaffer, 197 SETI Progress Report, Spaceflight, v. 19, September 1977 : 307–309.

[9] Patrick Palmer and Ben Zuckerman, Ozma II Search for Extraterrestrial Intelligence Abstract of a paper presented at the February 1976 annual meeting of the American Association for the Advancement of Science in Boston, Mass., p. 1.

[10] Ibid., p. 2.

very advanced scientific knowledge . . . . No immediate change in human society could be expected to result from this vast acquisition of advanced scientific knowledge. The effect would be to accelerate the inevitable trends of the social evolution of our biological society.[10]

—Roger MacGowan and Frederick Ordway III.

Arthur C. Clarke * * * has pointed out the difficulty of administering a galactic empire, be it benign or tyrannical, because the distances would make communications so very slow.[11]

—Arthur Clarke is a noted science fiction writer and scientist.

Interstellar contact would undoubtedly enrich our civilization with scientific and technical information which we could obtain alone only at very much greater expense. More than that, it is extremely likely that any civilization we detect would be more advanced than ours. Thus it would provide us with a glimpse of what our own future could be. From this we might learn the best course of action in planning the development of our own civilization without wasting time and resources through the trial-and-error approach, which has been until now our only available avenue to progress. * * * We need not be afraid of interstellar contact, for unlike the primitive civilizations on earth which came in contact with more advanced technological societies, we would not be forced to obey—we would only receive information.[12]

—Frank Drake, Director, National Astronomy and Ionosphere Center, Cornell University.

An inescapable conclusion is that, although such ships may be pursuing a peaceful intent, they would certainly be equipped with the highest level of technological armaments that their home society is capable of producing. Based on the past social history of this planet, which is one of our two basic premises, they are very likely to find hostile natives. * * * Under the limits of current physical theory, communication-dominant societies are restricted forevermore to only planetary systems surrounding a single stellar system. Far from being able to dominate the galaxy, the communicators will never dominate more than a single stellar system. To anyone that is revolted by the Big-Brother hypothesis, this can become a source of considerable philosophical satisfaction.[13]

—Maxwell Hunter II, Engineer, Lockheed Corp.

Given the probability that we will be dealing with a more advanced civilization, our posture should be one of calm confidence so that we appear neither offensive nor defensive.[14]

—Michael Michaud, U.S. State Department.

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[10] MacGowan and Ordway, op. cit., pp. 269–270.
[11] Sullivan, op. cit., p. 280.
[12] Frank Drake. On Hands and Knees in Search of Elysium, Technology Review, v. 78, June 1976: 24–25.
[13] Maxwell Hunter. In a speech at Foothill College, San Francisco, July 12, 1975.
[14] Michaud, op. cit., p. 76.

c. Other searches.—As shown in Figure 4–1, there have been several other attempts to detect radio signals, all meeting with a singular lack of success.

In the optical region of the spectrum, NASA's Orbiting Astronomical Observatory 3 (Copernicus) was used to search for ultraviolet laser signals from other civilizations. Herbert Wischnia, principal investigator for this experiment, studied the two Project Ozma stars as well as Epsilon Indi. By locating the receiver in space, the problem of absorption of ultraviolet radiation by the Earth's atmosphere is avoided (for further discussion of lasers as an interstellar communication mode, see section B.2.). The project was unsuccessful.

2. Proposed Systems

Most of the previously described systems could only detect a signal of great strength, such as a beacon or some other intentional signal specifically meant to be intercepted. Another possibility, though, is to eavesdrop on communications between two extant civilizations or on local transmissions of a planet such as television or commercial radio. This type of interception requires extremely powerful receivers, much larger than those used for Project Ozma and its successors, since the signal would probably be significantly weaker.

In 1971, NASA's Ames Research Center and Stanford University conducted a summer study to design such a system. Co-directed by Dr. John Billingham (NASA) and Dr. Bernard M. Oliver (Hewlett-Packard, on a summer appointment to Stanford), the group was charged with the task of assessing "what would be required in hardware, manpower, time and funding to mount a realistic effort, using present (or near-term future) state-of-the-art techniques, aimed at detecting the existence of extraterrestrial (extrasolar system) intelligent life."[11]

They concluded that a collecting area on the order of 7–20 square kilometers might be needed, representing a single antenna on the order of three to five kilometers wide, or more then ten times larger than Arecibo (see section B of this chapter).

> A single unit, Earth-based, steerable antenna of this size is out of the question. Even in space, where gravity forces could not crush it, nor winds overturn it, the cost of orbiting the thousands of tons of material needed, the problems of assembly and erection, and the logistics of maintenance, appear too formidable.[12]

Therefore the group chose a design consisting of many receivers, rather than a single dish (see figures 4–2 and 4–3).

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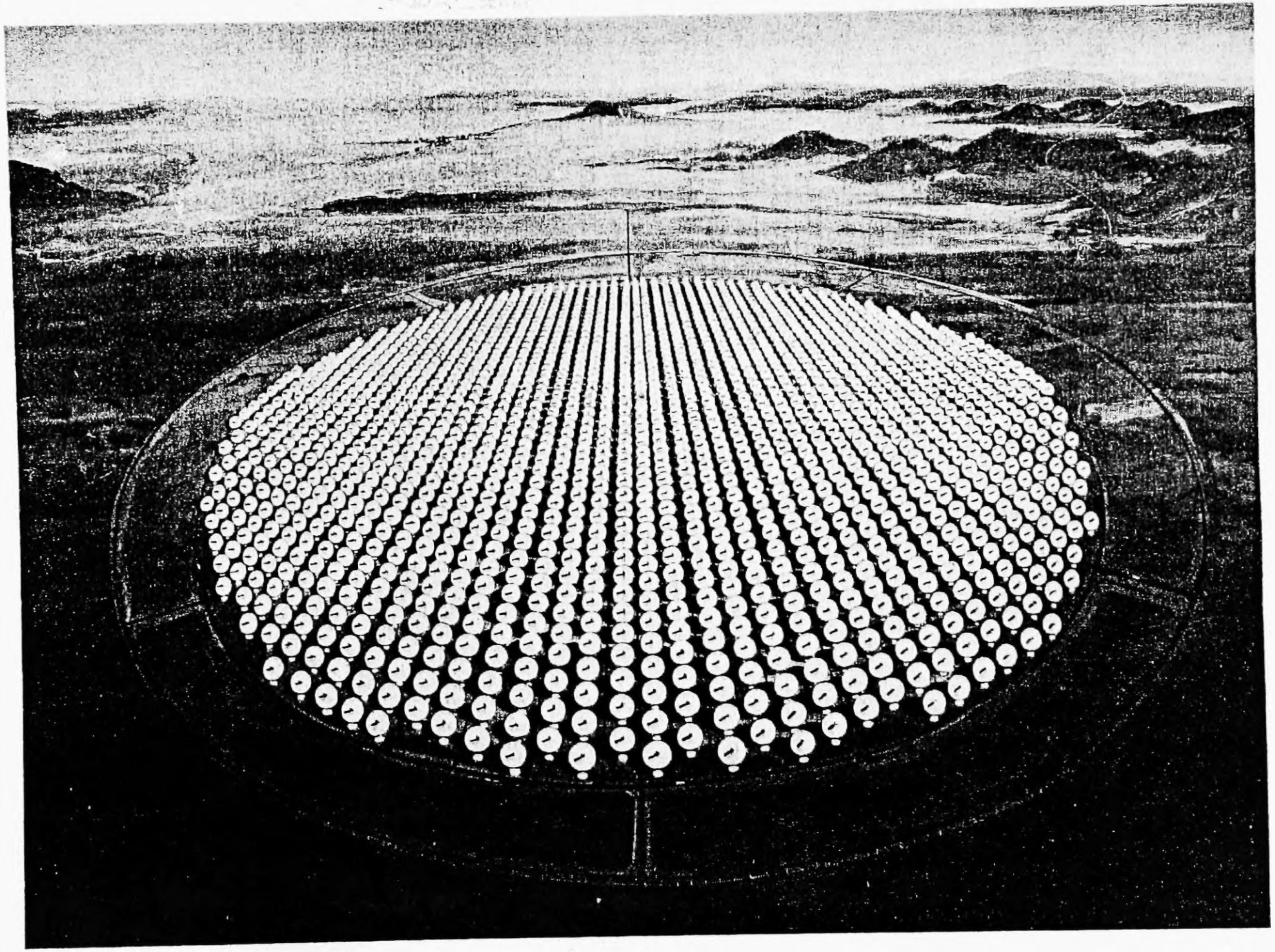
[11] Project Cyclops: A Design Study of a System for detecting Extraterrestrial Intelligence, Moffett Field, Calif., National Aeronautics and Space Administration, rev. ed., 1973: 1. Copies of this report are available from Dr. John Billingham, NASA Ames Research Center, Code LT, Moffett Field, Calif. 94035.

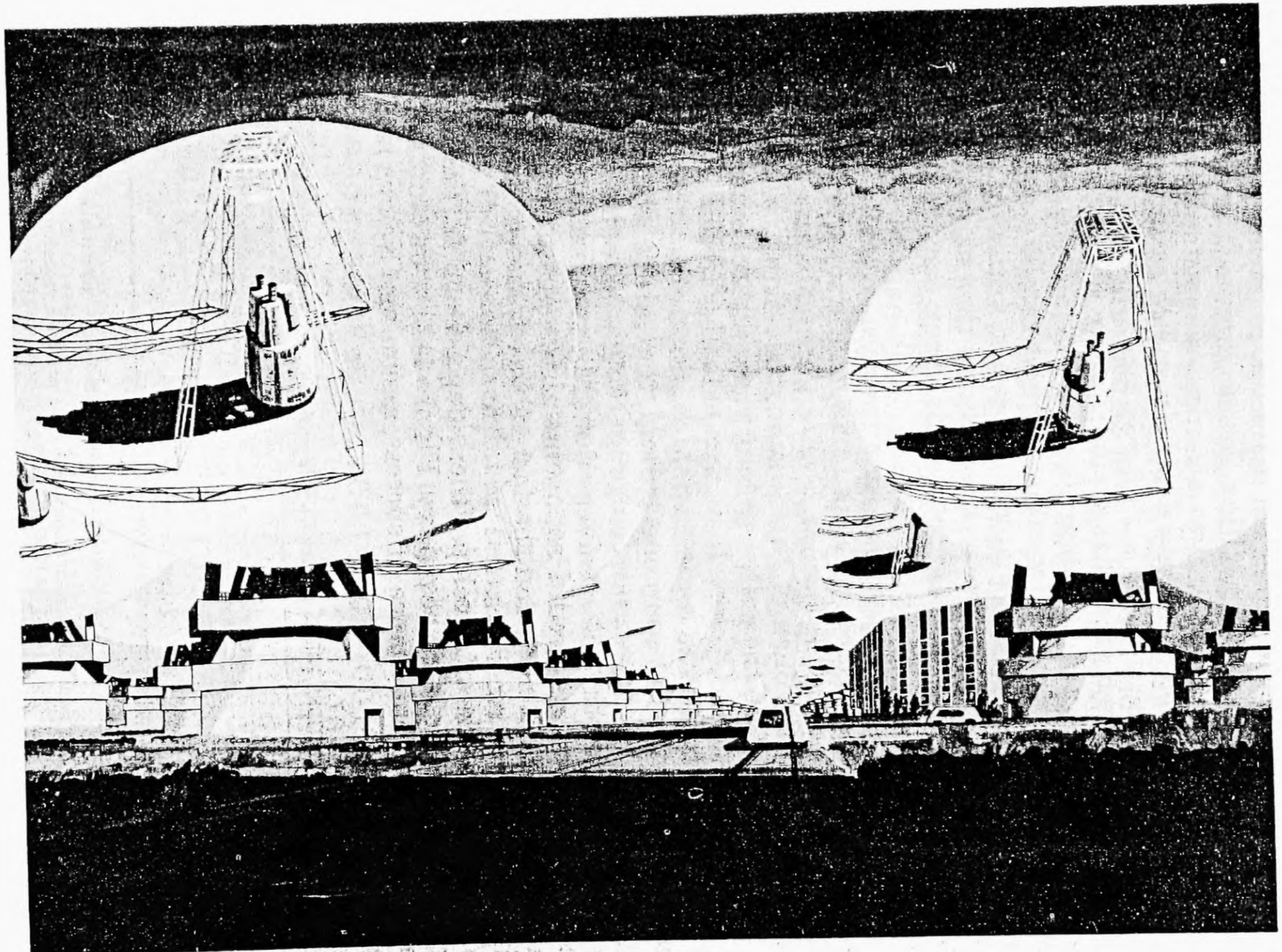
[12] Ibid., p. 67.

Figure 4-2.



Artist's conception of high aerial view of the entire Cyclops system. Diameter of the antenna array is about 16 kilometers. Photo courtesy of NASA.

Figure 4–3



Artist's conception of ground level view of Cyclops system antennas, showing the central control and processing building. Photo courtesy of NASA.

Named Cyclops, the system in its final form would consist of over 1500 antennas, each 100 meters in diameter, covering 65 square kilometers and costing up to $20 billion. Each antenna would be connected to all the other antennas and to a central computer which would be used both to position the array properly and to assimilate the individual signals into one signal.

There are some who feel that eavesdropping will not be productive, pointing out that Earth only started transmitting such signals 50 years ago, and 50 years from now cable TV and satellite communications may make the planet quiet again. Thus the transmitting time of a civilization may be comparatively short and the chances of our listening in at the right moment rather small. They consider the price tag too prohibitive.

Supporters counter, however, that the system could be used only half time for the signal search, and half time for other radio astronomy work. An array the size of Cyclops could be invaluable for all aspects of radio astronomy. In addition, they argue, success could be achieved long before the entire system was built. A commitment could be made to construct Cyclops by increments of 50 receivers. As soon as 10 or 15 were built, the search could begin and by the time the remainder of the first 50 were operational, the galaxy would already be explored out to 160 light years, encompassing 6,000 stars. If no contact were achieved, another 50 receivers would be commissioned, and so on until a signal was received. Proponents also suggest that signals may be falling on Earth now, and the fastest way to detect them would be with Cyclops-type receivers.

The ultimate size of Cyclops, then, depends on N, the number of technical civilizations in the galaxy. Figure 4–4 shows conditions necessary for a 63 percent chance of success, assuming Cyclops is used half time for the search.

FIG. 4-4.—CONDITIONS FOR 63 PERCENT CHANCE OF SUCCESS FOR CYCLOPS SYSTEM [1]

Number of civilizations	6,000,000	[2] 100,000
Number of years for search	2	25
Number of stars probed	6,000	500,000
Number of receivers required [3]	50	775
Cost	$1,870,000,000	$11,000,000,000

[1] Rough estimations only.

[2] If there are 1,000,000 civilizations, the figure accepted by most experts in CETI, there would be a 99-percent chance of contact in this scenario.

[3] Since the Cyclops study was made, advances in cooling have made possible a reduction of noise temperatures to 10° K, rather than 20° as reported then. This has the effect of doubling the system's sensitivity, thereby halving the needed size of the array.

In its report, NASA's Interstellar Communications Study Group Science Workshop panel emphasized again that Cyclops need never be built in its entirety for a search to be successful (see chapter 2, part D). The panel members recommended that at first, existing radio telescopes could be equipped with state-of-the-art receiving and data processing equipment, allowing adequate sensitivity for searches of nearby stars for transmitters similar to what we now have on Earth, as well as a broader search of the galaxy for more powerful signals, such as those from beacons. If these beginning steps prove unsuccessful, then a more ambitious program might begin. "If, after we have made such modest searches, it seems important to us to embark upon a more ambitious SETI program, such as contemplated by the Cyclops

study, the experience we will have gained will prove not only invaluable, but essential."[13]

In addition, technological advances since the Cyclops report was prepared have the effect of doubling the system's sensitivity, thereby halving the needed size of the array, and substantially reducing the projected costs. Factors such as problems with radio frequency interference (see part A. 4. of this chapter) could force scientists to build their antenna array either in space or on the moon. Until such time as an operational space shuttle system is available and experience has been gained in space construction, there is no realistic means of estimating the costs of such ventures. The 1977 NASA report comments: "Obviously, the whole question of Earth versus space based systems needs an order of magnitude more study before the issue can be resolved; this must be done before a commitment is made to any large search system. The possibility exists that a combination of ground and space systems would offer advantages not to be found in either alone."[14]

3. Language barriers

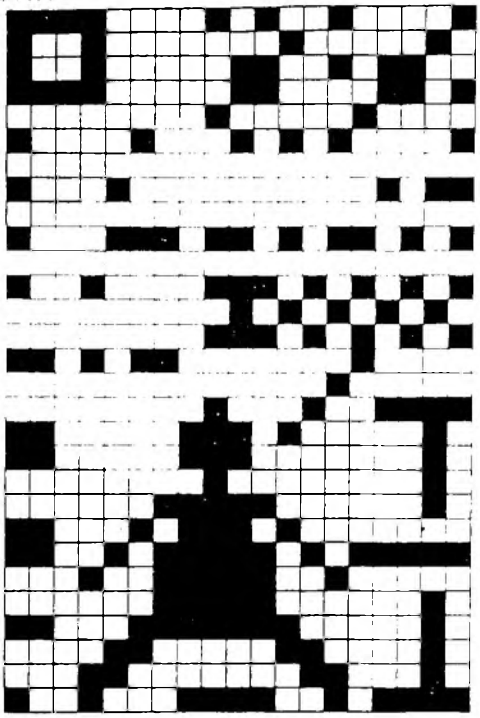
A problem that will be of great import should a signal ever be received is how to decode it. Without a common language, how could the two civilizations communicate? A good medium might be through pictures, as in the adage "a picture is worth a thousand words."

In conjunction with the 1961 meeting at Green Bank, Frank Drake composed a hypothetical interstellar message in binary code for the participants to decode. Each bit is translated into either a dark or light square. The message and its solution are shown below, along with Drake's explanation of the message's rationale and meaning.

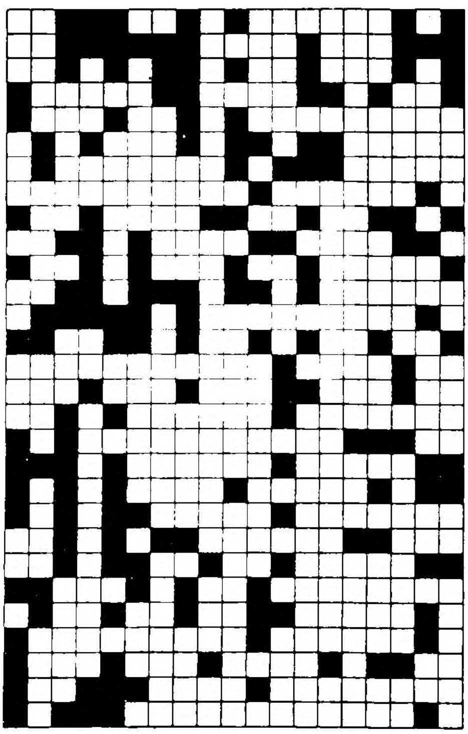
```
11110000101001000011001000000010000010100
10000011001011001111000001100001101000000
00100000100001000010001010100001000000000
00000000001000100000000001011000000000000
00000001000111011010110101000000000000000
00001001000011101010101000000000101010101
00000000011101010101110101100000001000000
00000000000100000000000001000100111111000
00111010000010110000011100000001000000000
10000000010000000111110000001011000101110
10000000110010111110101111100010011111001
00000000000111110000001011000111111100000
10000011000001100001000011000000011000101
001000111100101111
```

Frank Drake's hypothetical interstellar message in binary code.

[13] NASA, SETI: Search for Extraterrestrial Intelligence. NASA SP 419 [prepublication issuance] Moffett Field, Calif., NASA, 1977, p. 19.
[14] Ibid., p. 28.



The correct decoding of Figure 4–5. The 551 characters have been arranged into 29 groups of 19 characters, with ones represented as black spaces, and zeros as white spaces.



An incorrect deciphering of Figure 4–5. The characters here were placed into 19 groups of 29 characters.

The first step in the solution of this message is to determine, if possible, the number of dimensions in which the message is written. If one dimensional, it will be similar to an ordinary telegram; if two dimensional, it will be similar to a conventional TV picture, although other than Cartesian coordinates might be employed, etc. We would not expect the number of dimensions to be large, simply because ease of decipherment calls for few dimensions. To make headway in this, one may see what factors may be divided into 551. This test reveals that 551 is the product of only two factors, 19 and 29, both prime numbers, of course. This is a good indication that the message is two dimensional. Trial and error with Cartesian coordinates shows that breaking the message into 29 groups of 19 characters, and arranging these as in a conventional TV raster, gives a clearcut picture, which is obviously the correct decipherment of the message. Arrangement into 19 groups of 29 characters give the meaningless result shown in [Figure 4–7].

The interpretation of the picture is as follows:

1. The figure of the manlike creature at the bottom of the picture is obviously a drawing of the being sending the message. We see that it resembles a primate, with a heavier abdomen than we have, and that it carries its legs more widespread than we do. Its head is also more pointed than ours (or else it has a single antenna). One may speculate from this physiognomy that the gravitational acceleration is greater on the home planet of this creature than it is on earth.

2. The large square in the upper left-hand corner, accompanied by nine smaller objects strung along the left-hand margin, is a sketch of the planetary system of the creature. We see that there are four small planets, a larger planet, two large planets, another intermediate planet, and one last small planet. The system thus resembles our own in basic morphology.

3. The two groups in the upper right-hand corner may be recognized as schematic drawings of the carbon and oxygen atoms. We deduce from this that the creature's biochemistry is based on the carbon atom, as ours is, and that the oxidizer used in its chemistry is oxygen, also as with terrestrial animals.

4. A key group of symbols are those occurring just to the right of the four minor planets and the fifth planet. Inspection of these symbols shows that they are simply a modified binary representation of 1, 2, 3, 4, 5, written in sequence alongside the first five planets. The modification made to the basic binary numbers is the addition to the ends of the numbers of parity bits, where necessary, so that the number of 1's in every binary number is odd. This is similar to computer's practice on Earth. It is apparently not used here as a check on transmission, but rather to designate a symbol as a number. In future communications, symbols will certainly also be used for words of language. We may deduce from the creature's careful setting down of the binary number system that he will use this, with parity bits, for numbers henceforth.

It follows that we may expect words of language to have even numbers of 1's. In this way, the creature has established a number system and has enabled us to recognize words of language.

5. Knowing this, we may interpret the portions of the message located above the creature and below the atoms. We note that there are three groups of characters all having an odd number of 1's. These are then numbers. The lower group is connected to the creature by a diagonal line, signifying that it has something to do with him. We further note the arrangement of these groups are mutually consistent only if no parity bits are present. The lower group, which was too long to place on one line, is about $7x10^9$ in decimal notation. The next is about 3000, and the upper group is 11. Noting that these groups are connected to the creature, and written alongside planets 2, 3, and 4, we reach the apparent interpretation that these numbers are the population of the creature on those planets. There are about 7 billion creatures on planet 4, evidently the home planet. There are about 3000 on planet 3, from which we can deduce the fact that astronautics is more developed than on Earth, and there is a sizable colony on planet 3. Lastly, there are 11 of the creatures on planet 2, evidently a small scientific or exploratory group.

6. The figure to the right of the creature contains one binary number, and a symmetric configuration of symbols of even parity, probably not words, and certainly not numbers. One symbol is level with the top of the creature's head, and the other his feet. This is apparently telling us the size of the creature—it is 31 somethings tall. The only unit of length our two civilizations have in common is the wavelength at which the message was sent, so we conclude that the creature is 31 wavelengths tall.

7. Lastly, there is a symbol of even parity, with four 1's, underneath the creature. This is evidently an effort by the creature to use up all the "words" allotted him in his message. We may suspect, in keeping with the discussion in (4), that this is a word of language, and is very likely the symbol that the creature will use for himself in future messages. This behavior would seem to reinforce the conclusions of (4), but we will have to wait for future messages for proof that this conclusion is correct.

A few remarks:

The content of the message was designed to contain the data we would first like to know about another civilization, at least in the opinion of many scientists who have thought about this problem.

In preparing the message, an attempt was made to place it at a level of difficulty such that a group of high quality terrestrial scientists of many disciplines could interpret the message in a time less than a day. Any easier message would mean that we are not sending as much information as possible over the transmission facilities, and any harder might result in a failure to communicate. In trying this puzzle on scientists, it

has been true so far that scientists have understood the parts of the message connected with their own disciplines, but have usually not understood the rest. This is consistent with the philosophy behind the message.

The use of two dimensions has made possible the transmission of a great deal of information with few bits. This is because it is possible to arrange the symbols of the message in positions relative to one another such that even the arrangement carries information, when we employ logic and our existing knowledge of what may possibly occur in another planetary system. Thus the 551 bits are equivalent to approximately 25 English words, but the information content of the message appears much greater than that. This is because much of the message tells us, by the placement of a single symbol, which of several complicated possibilities is the one that has occurred in the other planetary system, without using bits to spell out precisely the possibility that has occurred.[15]

In order to transmit more specific information, however, a language is needed. Hans Freudenthal in Holland developed an appropriate language, Lingua Cosmica or LINCOS, free from grammatical inconsistencies and based entirely in the form of semantics. It is a coded system of units therefore cannot be spoken.

A sample transmission would begin with basic concepts in math and logic.[16] Using a series of radio pulses, the basic numbers are introduced: - represents the number 1; - - represents 2; - - - represents 3, etc. From this, other mathematical processes can be taught, such as 1+2=3, 1+3=4. This can also be used to teach fundamentals of human behavior.

A to B: How much is 15×15?
B to A: 15×15=220.
A to B: False.
A to C: How much is 15×15?
C to A: 15×15=225.
A to C: Correct.
C is more intelligent than B.

Shklovskii and Sagan feel that "a linguistic system based upon these fundamentals would be far easier to decipher than many of the written languages of ancient civilizations which have been deciphered by archaeologists."[17]

4. Radio frequency interference

A matter of grave concern to those scientists interested in conducting SETI searches is that if action is not taken soon, the radio spectrum will become so crowded that a message arriving from another civilization could not be detected. Radio waves are used not only for commercial radio and television, but for satellite transmissions (both to and from the spacecraft), radar, aeronautical and maritime navigation aids and so on. Two radio signals of the same frequency cannot usefully occupy the same space at one time; if they try, they interfere with each other (called radio frequency interference—RFI).

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[15] Reprinted with permission of Frank Drake, from original material republished in several sources.

[16] I. Shklovskii and C. Sagan, Intelligent Life in the Universe, San Francisco, Holden-Day, 1966, pp. 428–430.

The solution to SETI's RFI problem is to allocate a portion of the radio spectrum specifically for SETI (as distinct from radio astronomy) thereby preventing other services, such as satellites, from operating on those frequencies. As discussed earlier, however, one problem in conducting a SETI search is choosing the frequency to use, or in this case, what band of frequencies to attempt to preserve. Some scientists are convinced that the region bounded by the emission lines of hydrogen (1420 MHz)[18] and the hydroxyl radical (up to 1727 MHz) is the most probable region for interstellar communications (see page 48), and hence the first place to look. This region is often referred to as the "waterhole" since hydrogen (H) plus the hydroxyl radical (OH) equals water (H_2O).

Currently the waterhole is allocated to a variety of services, including meteorological and maritime satellites, as well as aeronautical navigation aids. The area from 1400 to 1427 MHz is allocated for radio astronomy. The Science Workshop on SETI, sponsored by the NASA Interstellar Communication Study Group (see page 31) adopted the following resolution calling for the allocation of the waterhole to SETI.[19]

> The Science Workshop, especially at its second, third, and fourth meetings, debated all considerations concerning whether the probability of finding signals from an extraterrestrial civilization is maximized in any particular frequency band. To the extent this problem requires knowledge of the motivation of such civilizations, it cannot be solved, but there are physical and philosophical arguments which imply that the frequency band between 1400 and 1727 MHz should have high priority for a search effort. Because of the sensitivity of any interstellar search system (ISS), it is very important that the only telecommunications services which operate in this band be those that will not cause harmful interference to an ISS. In 1979 a general World Administrative Radio Conference (WARC) will be held; it will allocate world-wide use of the radio spectrum and allocations made then are likely to determine spectrum usage for the remainder of this century. The Science Workshop recognized the importance of obtaining protection of the 1400 to 1727 MHz band for SETI use at the 1979 WARC and, to emphasize this need, adopted the following resolution.
>
> **STATEMENT ON THE REQUIREMENTS FOR PROTECTION OF AN INTERSTELLAR SEARCH SYSTEM (ISS) FROM RADIO-FREQUENCY INTERFERENCE**
>
> In recognition of the rapidly advancing national preparation for the 1979 general World Administrative Radio Conference (WARC), the Science Workshop adopts the following final statement of policy:
>
> 1. There are important frequency bands for a search for radio signals from extraterrestrial intelligent civilizations.

---

[18] One hertz (Hz) is equal to one cycle per second. A kilohertz (KHz) is 10^3 hertz; a megahertz (MHz) is 10^6 hertz; a gigahertz (GHz) is 10^9 hertz.

[19] Dr. Mark Stull, Protection of a Preferred Radio Frequency Band. In: NASA. SETI: Search for Extraterrestrial Intelligence, NASA SP 419, op. cit., pp. 195–196.

These are: (a) 1.400 to 1.427 GHz; (b) 1.427 to 1.727 GHz.

The 1.400 to 1.427-GHz band is of interest because interstellar transmissions may take place around the hydrogen line, while the 1.427 to 1.727-GHz band is located between the hydrogen and hydroxyl lines and lies near the minimum of the noise background. 1.400 to 1.427 GHz is currently alocated exclusively to the radio astronomy service and may be shared with it, while 1.427 to 1.727 GHz may be shared with services whose use will not cause harmful interference to the operation of an ISS.

2. Existing radio telescopes are already being used to search for radio signals from extraterrestrial civilizations, while the feasibility of constructing a very large ground-based ISS has been established. The performance of any ground-based instrument will, however, be seriously degraded by radio-frequency interference, primarily from line-of-sight transmitters. The only identified alternatives to an Earth-based ISS are: A space-based ISS; and an ISS sited on the far side of the Moon.

Both of these are possible in the future, but we do not know at what cost. Furthermore, a space-based ISS, unless shielded at additional expense, remains vulnerable to interference from satellite and ground-based transmitters; while an ISS on the far side of the Moon is vulnerable to all transmissions originating beyond the lunar orbit. Thus, there exists a need for RFI protection. We strongly recommend:

a. That the U.S. undertake immediate studies to determine detailed frequency protection requirements for an ISS, and submit the results of such studies to the 1977 Final Meeting of the International Radio Consultative Committee (CCIR) for inclusion in the supporting documents of the 1979 WARC, and

b. That the U.S. prepare and present to other administrations at the 1979 WARC a proposal which will include:

(i) Allocations for new satellite systems at frequencies outside the protected bands.

(ii) Appropriate frequency sharing criteria for uses compatible with the operation of an ISS.

(iii) Technical criteria for allowable spurious radiation from out-of-band uses.

(iv) Phase-out of interfering uses now operating in the protected bands.

Allocation of the radio spectrum in the international community is the responsibility of the International Telecommunications Union (ITU), a specialized agency of the United Nations based in Geneva, Switzerland. Figure 4–8 presents the organization of the ITU.

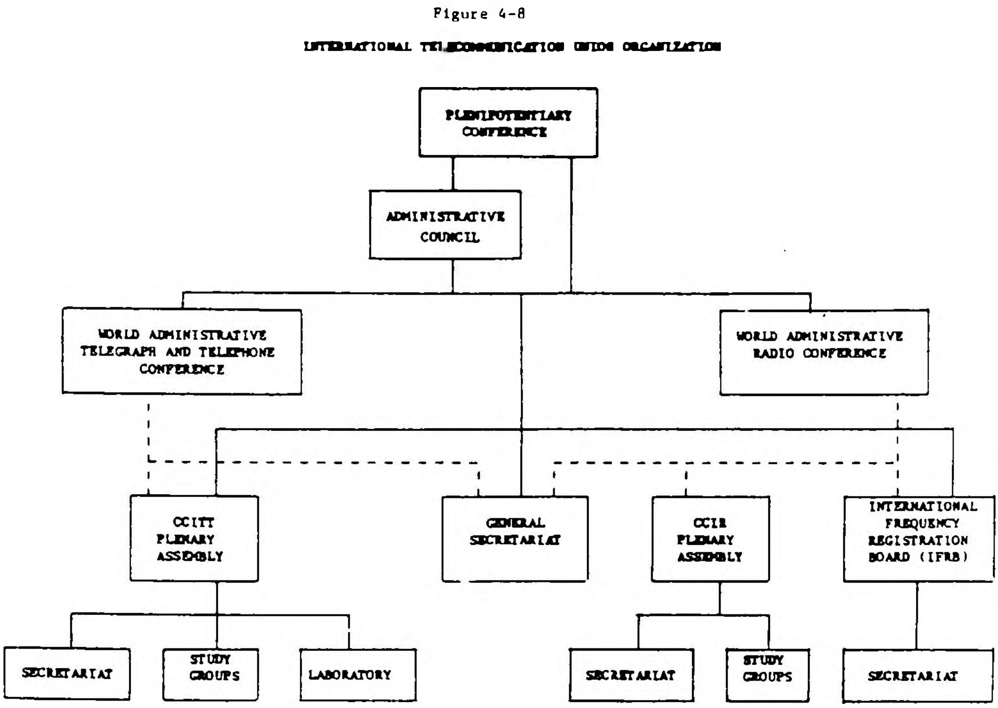

FIGURE 4–8.—International Telecommunication Union Organization.

The Plenipotentiary Conference, composed of representatives of the 146 Members and Associate Members, is the supreme organ of the ITU and usually meets at five year intervals to decide general policies, establish the basis for the budget, and elect officers. The Administrative Council, comprising 29 members selected to equitably represent all parts of the world, meets annually and acts for the Plenipotentiary in between meetings of that body.

The Administrative Conferences (either World or Regional) are held as needed to consider specific telecommunications matters. In 1947, the ITU made its first broad-based allocations, extending the Table of Frequency Allocations to 10,500 MHz (previously it had gone only up to 200 MHz). Twelve years later, an Ordinary Administrative Radio Conference was convened to expand those allocations up to 40 GHz. A World Administrative Radio Conference is scheduled for 1979 where the Table of Frequency Allocations will be reviewed and revised as necessary to reflect the burgeoning use of radio frequencies.

The CCITT (French initials for International Telegraph and Telephone Consultative Committee) studies and issues recommendations on technical, operating and tariff questions relating to telegraphy and telephony, while the CCIR (French initials for International Radio Consultative Committee) does the same for radio communications. The IFRB (International Frequency Registration Board) has responsibility for recording frequency assignments made by different countries and attempting to coordinate them in a manner which allows maximum use of the radio spectrum.

The ITU's General Secretariat, directed by a Secretary-General, is concerned with the administrative and financial aspects of the ITU, and coordinates the activities of the CCITT, CCIR and IFRB.

RFI is not an issue unique to SETI or radio astronomy (both of which are part of what are called the "passive services," indicating that they do not transmit signals, but only receive them); indeed it pervades the entire range of services using radio waves. Although the section of the electromagnetic spectrum which encompasses radio waves is quite large (up to 275 GHz), current technology allows use of only the lower 15 percent of those frequencies (up to 40 GHz); the region above 12–14 GHz is used experimentally. All radio services must therefore be accomodated in a rather small segment of the spectrum, at least for the present. The ITU's role in coordinating the conflicting requirements of different services and nations should not be underestimated. As with any organization established by treaty, though, the ITU has no enforcement powers, relying instead on voluntary adherence to its rules by signatory nations. This approach has worked quite well in the past since these countries have realized the necessity for cooperation in utilization of the finite natural resource called the electromagnetic spectrum. As more types of services are initiated and more nations vie for available frequencies, however, competition is certain to escalate.

One of the ITU's especially important roles is as a conduit for information between countries, primarily through its committees. For example, a nation desiring international study of a particular issue, such as SETI, can submit a "question" to the CCIR. If the proposed question receives more than twenty signatures from other CCIR members, it becomes an official part of the CCIR study program, and any country can prepare a response to the issues it raises. Subsequent meetings of the CCIR discuss those responses and a decision is made by the committee on whether or not to issue a formal recommendation to the full ITU. The ITU then decides what, if any, action to take.

The United States submitted a question to the CCIR on requirements for SETI systems. By November 1976 it had received the requisite signatures and became an official CCIR question numbered 17/2. The text of the question reads:

Question 17/2

RADIOCOMMUNICATION REQUIREMENTS FOR SYSTEMS TO SEARCH FOR EXTRATERRESTRIAL LIFE [20]

The C.C.I.R. (1976)

Considering

(*a*) that many scientists believe intelligent life to be common in our galaxy;

(*b*) that electromagnetic waves are presently the only practical means of detecting the existence of intelligent extraterrestrial life;

(*c*) that it is believed to be technically possible to receive radio signals from extraterrestrial civilizations;

(*d*) that, although it is not possible to know the characteristics nor to predict the time or duration of these signals in advance, it is reasonable to believe that artificial signals will be recognizable;

[20] Addendum No. 1 to Volume II, XIIIth P.A. of the C.C.I.R., Geneva, 1974.

(*e*) that, while an artificial radio signal of extraterrestrial origin may be transmitted at any frequency, it is technologically impractical to search the entire radio spectrum but the band searched should be sufficiently wide to make detection of a signal reasonably probable:

(*f*) that technological and natural factors which are dependent on frequency determine our ability to receive weak radio signals;

(*g*) that while the search for radio signals from extraterrestrial civilizations has already begun, more sensitive systems will be in use by the 1980's which could receive harmful interference from very weak man-made signals;

(*h*) that it is necessary to share the bands in which the search is conducted with other Services;

(*i*) that available technology will allow a search for these signals from the earth, from earth-orbit, and, eventually, from the moon and to minimize interference, certain locations on earth and in space may be preferred;

Decides that the following question should be studied

1. what are the most probable characteristics of radio signals which might be broadcast by extraterrestrial civilizations and the technical characteristics and requirements of a system to search for them;
2. what are the preferred frequency bands to be searched and the criteria from which they are determined;
3. what protection is necessary for receiving systems conducting a search for artificial radio signals of extraterrestrial origin;
4. what criteria will make operation of a search system feasible in shared, adjacent and harmonically related bands of other Services;
5. what is the optimum search method;
6. what are the preferred locations, on earth and in space, for a search system?

U.S. scientists hope this first step toward international cognizance of SETI RFI problems will lead to allocation of part of the spectrum for their purposes. To date, only the United States and Japan have prepared responses. These two reports, and any others that are received, will be discussed by the CCIR in 1977 and 1978. If the committee makes a recommendation to the ITU, it will be considered at the 1979 World Administrative Radio Conference.

Those scientists advocating reservation of the waterhole for SETI assert that services already operating on those frequencies can be tolerated; they only want to prevent future services from assignment to waterhole wavelengths. For example, three Marisat satellites (for maritime communications) currently operate on an uplink [21] of 1638.5–1642.5 MHz, and a downlink of 1537.0–1541.0 MHz. These Marisats would not be deactivated under this proposal, but follow-on Marisats would be assigned to frequencies outside the waterhole.

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[21] An uplink is communication from Earth to space; a downlink is communication from space to Earth.

There is a problem in waiting for the ITU to act until 1979, however: satellites are now in development that are scheduled for operation in the waterhole. Decisions affecting these spacecraft must be made prior to the 1979 WARC. One particular system of potential RFI for SETI is NAVSTAR, a global positioning system of 24 satellites situated so that at least six are accessible from any point on the globe. The satellites will broadcast signals continuously, which are picked up by receivers on airplanes and ships. Using small computers, those vessels can then determine their precise location.

One of NAVSTAR's downlinks lies in the middle of the waterhole, 1575.42 MHz (the other frequencies are downlink—1227.6 MHz 2227.5 MHz; uplink—1783.74 MHz). In addition, "spillover" into frequencies on either side of the prime frequency occurs with certain types of signals and creates additional interference (which is not regulated by any agency). This is expected to be a significant problem with NAVSTAR. If 24 satellites broadcast continuously at 1575.42 MHz, with a "broad-band" interference pattern, SETI searches will be impossible in that part of the spectrum. Some SETI enthusiasts are hopeful that if enough interest is evident, the Air Force (which is in charge of NAVSTAR) can be convinced or coerced into changing to another frequency. Such a decision ultimately rests with the White House Office of Telecommunications Policy, with responsibility for assigning frequencies to U.S. government users (the Federal Communications Commission handles public users).[22]

If attempts to reserve the waterhole for SETI are unsuccessful, there are three options for those who want to search for signals from other civilizations: (1) abandon the waterhole and find another part of the spectrum that might be used for interstellar communication—that is, use the next best bet; (2) build the receiving antenna in space (possibly at one of the Lagrange coordinates) and shield it from interference emanating from Earth; or (3) build the receiving antenna on the far side of the Moon. The first option may reduce the likelihood of detecting a signal, although all scientists do not agree that the waterhole is the most logical place to search. The other two alternatives would probably be prohibitively expensive, at least through the end of this century.

B. Sending Electromagnetic Signals

Attempts to detect signals from other civilizations can provide practical knowledge as to what should be included in any signal we might send into space to announce our existence. The signals could be either in the frequencies used by radio or those used by light via lasers.

1. *Radio*

In a sense, Earth has been "announcing" its existence for years, since transmissions from commercial radio and television are similar to those that would be deliberately sent. Large scale radio communication began about fifty years ago, meaning that a wave front of these emis-

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[22] The Carter Administration has indicated that it may reorganize the frequency allocation structure in the Federal Government.

sions is now about fifty light years distant, waiting to be detected by other beings. As Carl Sagan soberly observed:

> There are two general channels which are in heavy commercial use and which are transmitted by the terrestrial ionosphere * * * the entire television band [and] * * * the high frequency end of the AM broadcast band. * * * Thus the characteristic signs of life on Earth which may be detectable over interstellar distances include the baleful contents of many American television program and the mindless outpourings of rock-and-roll stations.[23]

Such signals are different from those which might be deliberately transmitted, however, especially in terms of message content. They do not include information from which aliens could specifically identify the planet (or solar system) of origin, nor do they relate details of the genetic code for homo sapiens. Serious consideration would need to be given to deciding whether messages involving such detailed information should be sent, for the receiving civilization might be capable of interstellar flight and dispatch emissaries for further investigation. With no foreknowledge of their character, we might be aiding in our own doom. Although it is tempting to hypothesize that any civilization advanced enough to have conquered the difficulties of interstellar flight would have also overcome the petty differences that spawn wars, that same civilization might not be certain that we would be peaceful. Previous experience with warlike peoples might have convinced them to arrive at a new planet well armed and ready for combat. Potential repercussions arising from contact with extraterrestrial intelligence are discussed in Chapter 5, but since radio and television waves are already wafting out into space, our choices might be restricted.

a. The Arecibo message.—In point of fact, a discussion of the merits and demerits of announcing our existence to the universe at large is somewhat academic, since it has already been done. On November 16, 1974, Frank Drake and Carl Sagan transmitted the first intentional announcement signal from the Arecibo Observatory (see Figure 4–9) in Puerto Rico. Drake, who headed Project Ozma in 1960, is currently director of the National Astronomy and Ionosphere Center at Cornell University which operates Arecibo for the National Science Foundation. The message, depicted in Figures 4–10 and 4–11, was composed by Drake and Sagan, and took less than three minutes to transmit.

> "This coded signal starts with a simple lesson on how to count and then very carefully describes the chemistry of life on Earth," said Dr. Frank Drake. * * *
>
> "It tells how complex we are, what our genetic material is. It also tells how advanced we are, by telling in code bits the structure, growth, and brain of a human being."[24]

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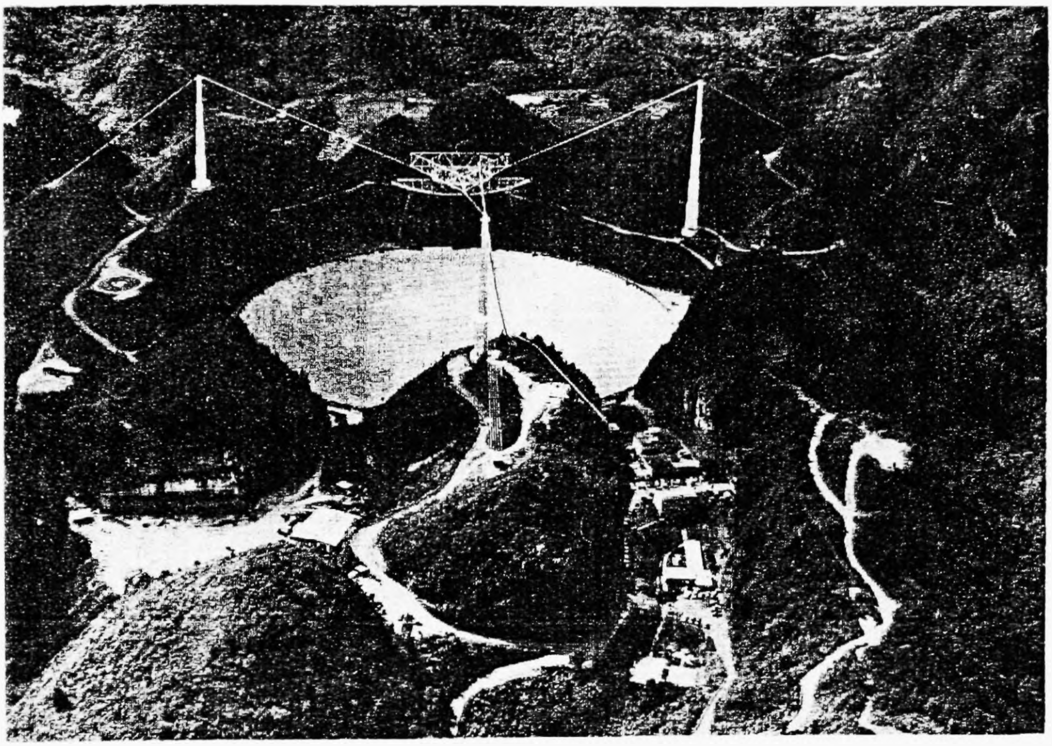
[23] Shklovskii and Sagan, op. cit., pp. 393–394.

[24] Quoted in: Thomas O'Toole, "Beam Sent to Find Other Civilization," Washington Post, Nov. 17, 1974: 1.



The Arecibo Radio Telescope, located at Arecibo, Puerto Rico. Photo courtesy of the National Science Foundation.

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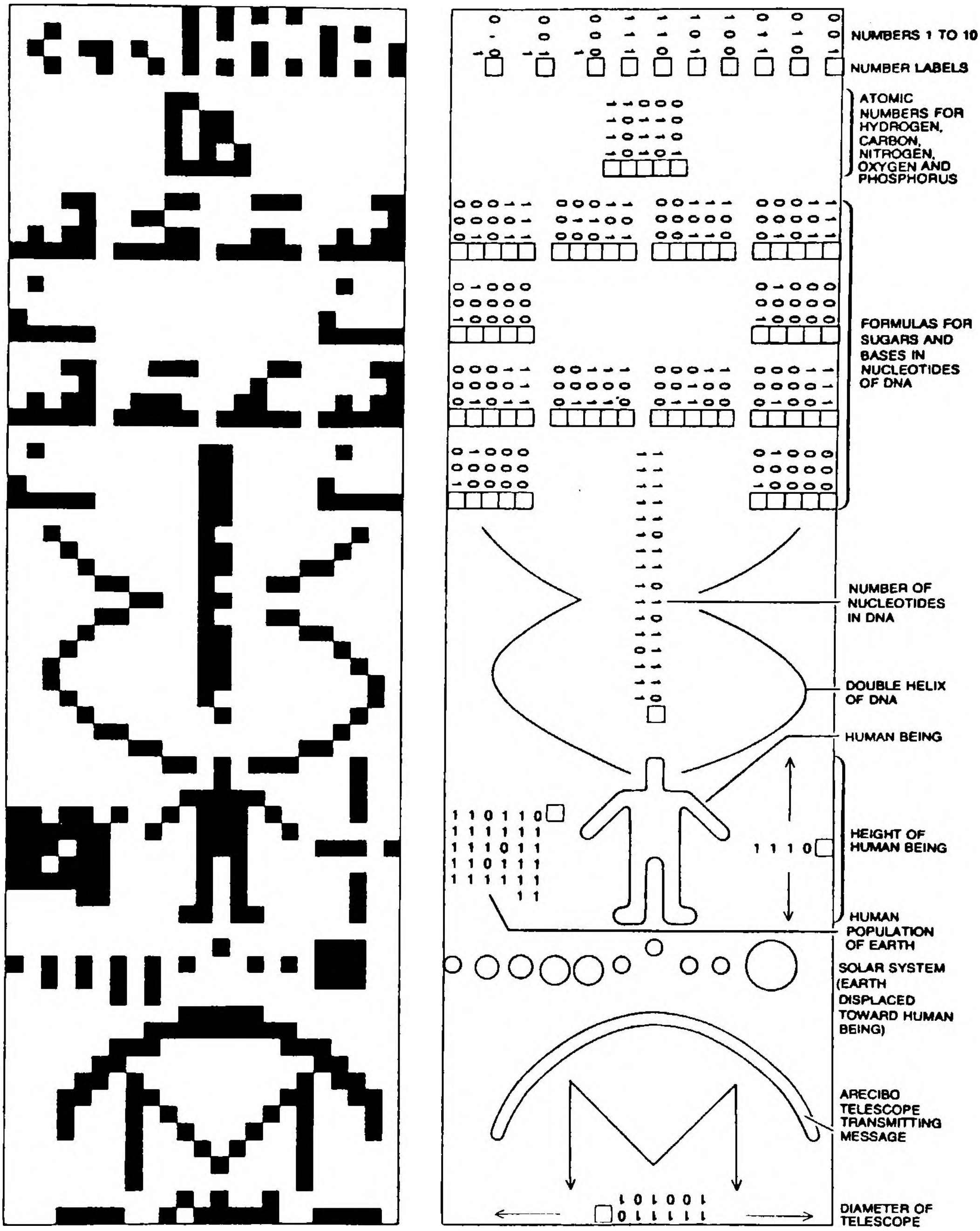
Arecibo message in binary code. Source: Carl Sagan and Frank Drake. Search for Extraterrestrial Intelligence. Scientific American, v. 232, May 1975: 86. Reprinted with permission, copyright 1975 by Scientific American.



Arecibo message in pictures. Source: Carl Sagan and Frank Drake. Search for Extraterrestrial Intelligence. Scientific American, v. 232, May 1975: 87. Reprinted with permission, copyright 1975 by Scientific American. All rights reserved.

The signal was not aimed at one of Drake's Project Ozma stars, but rather at the Great Cluster in Hercules, a group of 300,000 stars called Messier 13. This target was selected because at its distance from Earth (24,000 light years) it has the same angular size as the beam will have at that distance. Thus all the stars in the cluster will receive the signal. Sagan estimated a 50–50 chance of a civilization existing

there. With a round trip travel time of 48,000 years before a comparable radio message could reach Earth, concern for the safety of the planet is not overwhelming.

The binary coded message (Figure 4–10) is solved by putting the figures into 70 consecutive groups of 23 characters. Translating each "0" into a white square and each "1" into a black, a visual message appears (Figure 4–11), reading right to left and top to bottom:

> Each number that is used is marked with a label that indicates its start. When all the digits of a number cannot be fitted into one line, the digits for which there is no room are written under the least significant digit. (The message must be oriented in three different ways for all the numbers to be read.) The chemical formulas are those for the components of the DNA molecule: the phosphate group, the deoxyribose sugar and the organic bases thymine, adenine, guanine and cytosine. Both the height of the human being and the diameter of the telescope are given in units of the wavelength that is used to transmit the message: 12.6 centimeters.[25]

2. Laser

Contacting other worlds by beaming a light in their direction was considered the only feasible way of attracting attention before the advent of radio. But light dissipates rapidly (due in part to the fact that it is difficult to have the beams emitted exactly parallel to each other) so the signal would not travel very far before becoming indistinguishable from other light in the universe. That is, until the laser was invented.[26]

Lasers are intense, narrow beams of light, and since they can be transmitted from very narrow apertures, they dissipate less rapidly and can be pulsed at powers up to 50,000,000 watts. Using a filter, a monochromatic (single color) beam is possible.

A major problem to overcome is to make the laser light distinguishable from the light which emanates from the Sun. R. N. Schwartz and C. H. Townes of the Massachusetts Institute of Technology suggested in 1961 that though there is "some, but little hope of resolving the two spatially . . . one [could] resort to high spectral resolution in order to discriminate between [laser] and stellar radiation." [27] This is why a monochromatic (i.e., ultraviolet) beam is advantageous. As mentioned previously, NASA's Copernicus satellite was used to search for ultraviolet laser beams in 1974 and 1975 with no success.

Transmitting in certain spectral lines would have advantages over others.

> The spectral intensity of the Sun at wavelengths greater than 15,000 angstroms or less than 2,500 angstroms is more than 10 times less than at 5000 angstroms; at wavelengths greater than 40,000 angstroms or less than 2000 angstroms, it is hundreds of times less than at 5000 angstroms.
>
> . . . If a laser operating near 1500 angstroms could be sent aloft in a satellite [so the atmosphere would not absorb the

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[25] Sagan and Drake, op. cit., p. 87.

[26] Laser stands for Light Amplification by Stimulated Emission of Radiation and is also known as an optical maser.

[27] R. N. Schwartz and C. H. Townes, Interstellar and Interplanetary Communication by Optical Maser. In A. G. W. Cameron, Interstellar Communication, New York, Benjamin Inc., 1963, p. 226.

light] * * * it could attain a spectral intensity some tens of thousands of times greater than that of the Sun.

...With a power level of millions of kilowatts, a laser beam which fills the entire inner solar system of the target star would be useful for interstellar contact over hundreds of light years.[28]

C. Unmanned Probes

Radio and light waves travel at the speed of light, the fastest known method of communication over the vast interstellar distances. There are other methods of interstellar communication, however, such as sending unmanned probes or manned ships. This section discusses the former.

1. *The Bracewell model*

Ronald Bracewell, a radio astronomer at Stanford University, suggested as early as 1960 that radio signals are an uneconomical way to contact other civilizations, recommending unmanned automatic probes as an alternative.[29]

He envisions a galactic communication network linking many established technical civilizations. The nearest one to our solar system would spray an area of some thousand stars with "modest" probes which would enter circular orbits around their destination stars, within the habitable zone. "Such a probe may be here now, in our solar system, trying to make its presence known to us."

The process foreseen by Bracewell would have the probe equipped with a radio transmitter. It would listen for intelligent radio signals from us, discovering what wavelength to transmit on, and then repeat what it had heard back to use. On Earth, these signals would appear as echoes with a delay factor of seconds or minutes, depending on how far away the probe was, "such as were reported 30 years ago by Stormer and Van de Pol and never explained."

We would eventually recognize that a probe was trying to contact us, and respond by repeating the message once more to let the probe know we were aware of it. The probe would then begin transmitting its message, with occasional checks to ensure it had not set below the horizon. Bracewell suggests that the first message might be a television image of a constellation showing the probe's home port.

Since the probe might have to journey to several stars before finding an intelligent civilization, it would also be equipped to collect other useful information in the manner that our Mariner and Pioneer spacecraft do. Thus, even if a probe had entered our solar system long before our radio era began, it might still be in the area conducting other investigations.

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[28] Shklvoskii and Sagan, op. cit., pp. 403, 406.

[29] Ronald Bracewell, Communications from Superior Galactic Communities. In A. G. W. Cameron, Interstellar Communication, New York, Benjamin Inc., 1963, pp. 243–248.

In a 1974 publication, Bracewell expands his argument into the political ramifications of such a contact. "It would be naive to think that an alien probe could count on delivering its message freely to the inhabitants of the Earth." [30] The probe would have to be prepared with "sociological resourcefulness" to insure that it did not get trapped into communicating with only one agency or country. Bracewell paints the following scenario, which although somewhat nationalistic, is conceivable:

At some point, the probe would set below the horizon and the original recipient of the message would have to hand over control to another station. NASA offers suitable world-wide facilities for the United States, but if France or England intercepted the first message, confusion and disorganization could result. The probe would probably have a plan to identify a competent entity to communicate with and could enlist NASA's cooperation simply by reducing its signal level until those countries without our technical capability would have to drop out. Those nations would then probably accept an offer from the United States to form international teams to operate the NASA sites, but if not, NASA would have to defer to them or risk having the frequency jammed. "The contingency plans of the probe would need to provide for rivalry." After the probe had completed its message and each side had learned the basics of each other's language, we would begin communicating with the home star directly, using the probe as translator if necessary.

2. Pioneer and Voyager

Earth has already sent its first interstellar messages by unmanned probe, although they are not of the same description as Bracewell's plan. Pioneer 10, which provided the first good look at Jupiter, and its sister Pioneer 11, now enroute to Saturn, will both eventually leave the solar system. Aboard them are six inch by nine inch (152 by 229 millimeter) plaques designed by Carl Sagan and Linda Saltzman Sagan (see figure 4–12) pictorially describing their point of origin and basic characteristics of the senders. Even though the ships are the fastest vehicles ever launched, one would not reach the nearest star for 80,000 years, if in fact it were headed in that direction, which neither are. The best chance for one of the plaques reaching another civilization is if that race travels in interstellar space and one of their ships picks it up. "Placing a message aboard Pioneer 10 is very much like a shipwrecked sailor casting a bottled message into the ocean—but the ocean of space is much vaster. * * *" [31] Sagan's explanation of the plaque follows:

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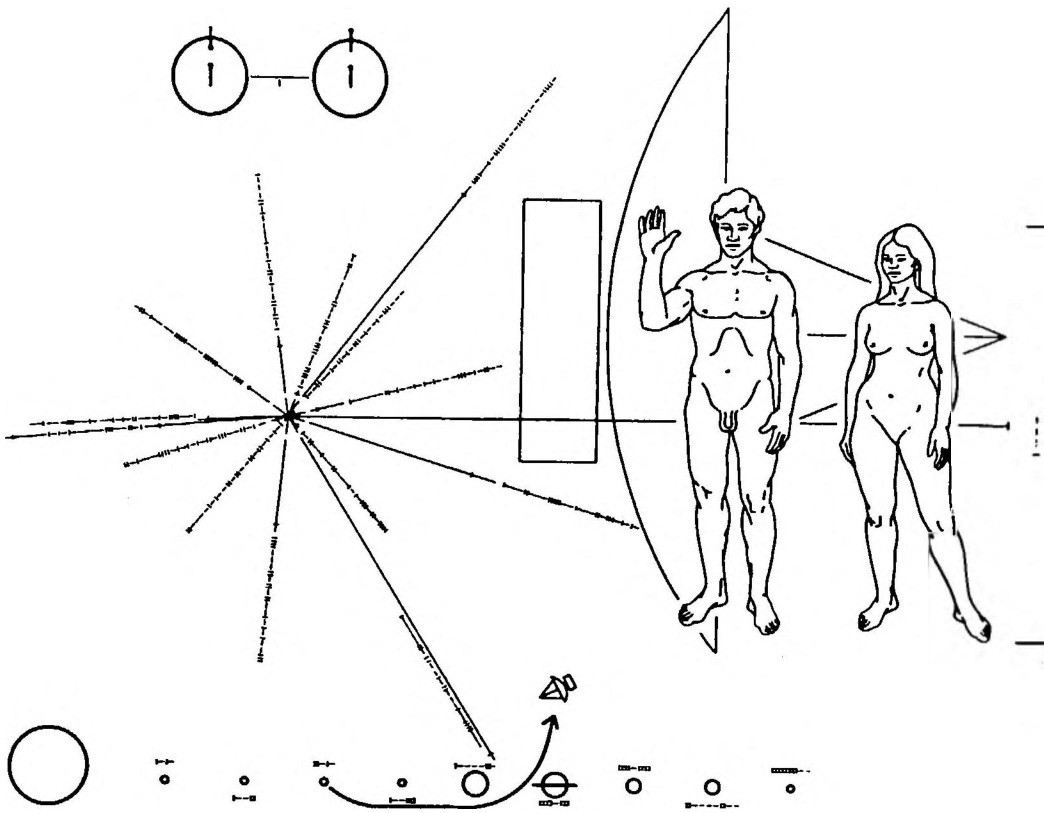
[30] Ronald Bracewell, The Galactic Club, Stanford, Calif., the Stanford Alumni Association, 1974, p. 75.
[31] Carl Sagan, The Cosmic Connection, New York, Anchor Press, 1973, pp. 17–18.



Pioneer 10 plaque. Photo courtesy of NASA.

The message itself intends to communicate the locale, epoch, and something of the nature of the builders of the spacecraft. It is written in the only language we share with the recipients: Science. At top left is a schematic representation of the hyperfine transition between parallel and antiparallel proton and electron spins of the neutral hydrogen atom. Beneath this representation is the binary number 1. Such transitions of hydrogen are accompanied by the emission of a radio-frequency photon of wavelength about 21 centimeters and frequency of about 1,420 Megahertz. Thus, there is a characteristic distance and a characteristic time associated with the transition. Since hydrogen is the most abundant atom in the Galaxy, and physics is the same throughout the Galaxy, we think there will be no difficulty for an advanced civilization to understand this part of the message. But as a check, on the right margin is the binary number 8 (1 – – –) between two tote marks, indicating the height of the Pioneer 10 spacecraft, schematically represented behind the man and the woman. A civilization that acquires the plaque will, of course, also acquire the spacecraft, and will be able to determine that the distance indicated is indeed close to eight times 21 centimeters, thus confirming that the symbol at top left represents the hydrogen hyperfine transition.

Further binary numbers are shown in the radial pattern comprising the main part of the diagram at left center. These numbers, if written in decimal notation, would be ten digits long. They must represent either distances or times. If distances, they are of the order of several times 10 centimeters, or a few dozen times the distance between the Earth and the Moon. It is highly unlikely that we would consider them useful to communicate. Because of the motion of objects within the Solar System, such distances vary in continuous and complex ways.

However. the corresponding times are on the order one-tenth second to 1 second. These are the characteristic periods of the pulsars, natural and regular sources of cosmic radio emission; pulsars are rapidly rotating neutron stars produced in catastrophic stellar explosions. We believe that a scientifically sophisticated civilization will have no difficulty understanding the radial burst pattern as the positions and periods of 14 pulsars with respect to the Solar System of launch.

But pulsars are cosmic clocks that are running down at largely known rates. The recipients of the message must ask themselves not only where it was ever possible to see 14 pulsars arrayed in such a relative position, but also when it was possible to see them. The answers are: Only from a very small volume of the Milky Way Galaxy and in a single year in the history of the Galaxy. Within that small volume there are perhaps a thousand stars; only one is anticipated to have the array of planets with relative distances as indicated at the bottom of the diagram. The rough sizes of the planets and the rings of Saturn are also schematically shown. A schematic representation of the initial trajectory of the spacecraft launched from Earth and passing by Jupiter is also displayed. Thus, the message specifies one star in about 250 billion and one year (1970) in about 10 billion.[32]

Much of the discussion about the plaque here on Earth focused on the nudity of the man and woman. Sagan reported that some of the media printing the picture omitted the nipples on the woman and the genitalia on the man. As a letter in the Los Angeles Times irately stated:

I must say I was shocked by the blatant display of both male and female sex organs on the front page of the Times. Surely this type of sexual exploitation is below the standards our community has come to expect from the Times.

Isn't it enough that we must tolerate the bombardment of pornography through the media of film and smut magazines? Isn't it bad enough that our own space agency officials have found it necessary to spread this filth even beyond our own solar system? [33]

Others complained that the man's upheld hand might convey militance (if, for example, the radio transmissions of Nazi Germany had

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[32] Ibid., pp. 18–20. Reprinted with permission. Copyright 1973 by Carl Sagan.
[33] Quoted in: Ibid., p. 25.

preceded this message wherein the outstretched hand was a symbol of Hitler's followers), and Catholic groups noted the plaque "includes everything but God."

3. Voyager 1 and 2

In the fall of 1977, the United States launched two Voyager spacecraft to Jupiter and Saturn (see figure 1–3; note that Voyager was previously designated Mariner Jupiter-Saturn). Since these probes will also leave the solar system, Sagan and his colleagues did not waste the opportunity to send further messages to possible alien civilizations. Instead of a plaque, however, a two-hour record was made onto a copper disc and attached to the side of each spacecraft, together with a needle and instructions on how to operate the device. The record contains electronically transcribed photographs, messages of greetings in many Earth languages, and sounds of the planet and its inhabitants. A listing of the program on the record appears as Appendix C.

The 115 photographs show Earth's environment (such as islands, mountains, deserts and valleys), its inhabitants (human and other animals), and its artifacts (such as supermarkets and superhighways). Following on criticism of the "smut" on the Pioneer plaques, NASA was more cautious in approving the photographs for this interstellar message, and one picture of naked human beings (provided ostensibly to demonstrate the reproductive system) was disallowed. Possible legal entanglements, together with concern about criticism, led NASA officials to omit that photograph; NASA associate administrator for external affairs, Herbert Rowe, was quoted as saying "We didn't think that as far as the aliens were concerned the picture was needed to tell the story." [34]

The record next provides greetings in sixty different languages (see Appendix C for complete listing), including one from United Nations Secretary General Kurt Waldheim, and another from United States President Jimmy Carter. The Carter message was not vocally recorded, but rather would be converted into written words. Carter's message reads:

> This Voyager spacecraft was constructed by the United States of America. We are a community of 240 million human beings among the more than 4 billion who inhabit the planet Earth. We human beings are still divided into nation states, but these states are rapidly becoming a single global civilization.
>
> We cast this message into the cosmos. It is likely to survive a billion years into our future, when our civilization is profoundly altered and the surface of the Earth may be vastly changed. Of the 200 billion stars in the Milky Way galaxy, some—perhaps many—have inhabited planets and spacefaring civilizations. If one such civilization intercepts Voyager and can understand these recorded contents, here is our message:
>
> "This is a present from a small distant world, a token of our sounds, our science, our images, our music, our thoughts, and our feelings. We are attempting to survive our time so

[34] NASA Bans Sex from Outer Space, Science, Sept. 16, 1977 : 1163.

we may live into yours. We hope someday, having solved the problems we face, to join a community of galactic civilizations. This record represents our hope and our determination, and our good will in a vast and awesome universe." [35]

The message recorded by Secretary General Waldheim states:

As the Secretary General of the United Nations, an organization of 147 member states who represent almost all of the human inhabitants of the planet Earth, I send greetings on behalf of the people of our planet. We step out of our solar system into the universe seeking only peace and friendship, to teach if we are called upon, to be taught if we are fortunate. We know full well that our planet and all its inhabitants are but a small part of the immense universe that surrounds us and it is with humility and hope that we take this step.[36]

The photographs and greetings consume about 30 minutes; the remaining 90 minutes are devoted to 27 musical selections representing different areas of the world. Included are movements from Bach, Beethoven, Mozart and Stravinsky, "Flowering Streams" from China, "Jaat Kahan Ho" from India, a Navajo Indian Night Chant, a Bulgarian Shepardess Song, "Melancholy Blues" by Louis Armstrong, and "Johnny B. Goode" by Chuck Berry (a complete listing can be found in Appendix C).

As with the Pioneer spacecraft, the only real chance Voyager has of delivering its messages is if another civilization travels in interstellar space and picks it up. Then the aliens would have to determine how to work the "record player."

4. Project Daedalus

In 1973 the British Interplanetary Society set up Project Daedalus to study the feasibility of sending an unmanned probe to a nearby star using science and technology expected to be available by the year 2000. The simplest mission model, a one-way undecelerated flyby, was chosen and Barnard's Star was selected as a target, since it is only six light years distant. This would permit a travel time of only about 40 years, allowing some of those involved with the probe's launch to also be associated with the completion of the mission.

The group decided that a nuclear pulse rocket with external ignition was the only type of propulsion expected to be available by the end of the century capable of accomplishing the mission. An exhaust velocity of 10^7 meters per second is expected to be achievable, with a boost period of five years, and then thirty-five years of coasting at about 0.167 speed of light. Taking several factors into account, a payload weight of 500 tons was calculated to produce the lowest cost, although specifics about what would be carried on the probe have not been determined.

The communications system would use microwave frequencies with the reaction chamber of the small engine serving as an antenna. This system is within the range of present technology. Navigation would be accomplished by using nearby stars as reference points, with a Siriusfinder available as a backup in case the ship became disoriented.

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[35] From NASA Press Release 77–159, Voyager Will Carry "Earth Sounds" Record, Washington, D.C., NASA, Aug. 1, 1977 : 11.
[36] Ibid., p. 12.

Studies on possible propulsion systems, modes of communication, and possible payloads are continuing. The British Interplanetary Society announced in the fall of 1977 that a special report would be issued within the next year on Project Daedalus detailing study proposals and results so far achieved.[37]

D. Manned Ships

As exemplified by the tales of Icarus and Daedalus, man's desire to take to the skies has existed for centuries. It has only been in this century, however, that we have been able to fly not only within the Earth's atmosphere, but outside its gravitational control. If we can travel to the Moon, why not to the stars?

Several methods of contacting other civilizations have been discussed, but none holds the same intrigue as actual physical contact. To begin with, the time involved in radio communication is enormous—it will be 48,000 years before we know if anyone in Messier 13 received the message sent out from Arecibo in 1974. There may be no one left on Earth to receive the answer, and all would have been in vain. But with manned spaceflight, there would at least be the crew members or their descendants to carry tales of Earth; our culture and knowledge could survive.

Unfortunately, the distances involved are the same and the speed at which we could travel would be slower than electromagnetic signals; Einstein's theory of relativity does not permit objects to travel at or faster than the speed of light (designated "c"), per the formula:

$$m=\frac{m_0}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$

where m is the final mass, m_0 is rest mass, v is velocity and c is the speed of light. If one's velocity is the speed of light ($v=c$), then

$$\frac{v}{c}=1;\ 1^2=1;\ 1-1=0;\ \text{and}\ \sqrt{0}=0$$

Anything divided by 0 is infinity. Thus as an object reaches the speed of light, its mass becomes infinite.

If the necessary propulsion systems were available, then, the fastest man could travel would be 0.99 c, and the round trip travel time to the nearest star would be more than eight years. In order to have a reasonable chance of contacting another civilization, plans would have to assume traveling many, many more years than that, raising the question of how to do so within man's short lifetime.

1. Propulsion systems

Of the several future space propulsion methods receiving serious consideration by scientists, the three most often discussed are: nuclear fusion, an interstellar ramjet using atoms in interstellar space as fuel, and a matter-antimatter reaction.

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[37] Spaceflight, v. 19, September 1977: 312.

The speed at which a rocket travels primarily depends on two things: its exhaust velocity (the speed with which the propellant burns and throws energy out the back), and its mass ratio (initial mass—how much it weighs without the fuel and other consumables, e.g. the payload and spent rocket casing). Thus the more one wants to launch, the more fuel is needed and the more the spaceship weighs.

a. Fusion.—The fusion reaction used in hydrogen bombs converts deuterium (heavy hydrogen) into helium and a great amount of energy. Present technology is not capable of controlling this reaction (being able to stop and restart it at will), so it is not used as a source of power. If a controlled reaction were possible, though, it might not only solve Earth's energy problems, but could propel spaceships with an exhaust velocity of $\frac{1}{8}$ *c* (assuming the burn was accomplished with 100 percent efficiency).

This is the best known fusion reaction in nature, and its main drawback is that in order to attain a speed near *c*, the initial mass of the spacecraft would have to be approximately one billion times its final mass; that is, to launch a one ton payload, one would have to start off with a billion tons.[38] This is an obvious disadvantage.

Dr. Conley Powell of the Department of Mechanical Engineering, University of Kentucky, disregards the need to travel near *c* and derives a formula for speeds which require centuries for a ship to reach its destination, confident that the problems of man's short life time will be resolved. He feels that even though "high-acceleration, near-light-speed drives" are not possible today, "fusion drives, which require no fundamental advances . . . can take us to the nearer stars with flight times no longer than a few centuries." [39]

b. Interstellar Ramjet.—Robert V. Bussard of TRW Inc., Los Angeles, first promoted this theory in 1960. By his reasoning, the spaceship would use atoms in the interstellar medium both as a reaction mass and as an energy source through fusion (note that the ship would have to begin its journey with the aid of fusion powered stages).

Although Bussard's idea violates no laws of physics, it does have a major problem: to scoop up the interstellar material required, an enormous intake area is needed. Carl Sagan calculates that in ordinary space with one hydrogen atom per square centimeter, the sweeping system would have to be 2,500 miles (4,000 kilometers) in diameter.[40] He suggests that since hydrogen clouds have a density possibly as high as 1000 particles per cubic centimeter, the collecting area could be only 80 miles wide, and ships could dart from cloud to cloud.

Another alternative is to have non-material collecting areas, that is, magnetic fields which guide ionized particles into the intake area. These fields could also be used to deflect the atoms from the spacecraft's body, solving the insulation problem. At near *c*, dust and atoms would strike the ship at 2×10^{11} ergs per square centimeter per second, an intensity more than 100,000 times that of sunlight on Earth's surface. "The occupants would fry." [41]

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[38] See: Edward Purcell, Radioastronomy and Communication Through Space. In A. G. W. Cameron, Interstellar Communication. New York, Benjamin Inc., 1963, p. 137.

[39] Dr. Conley Powell. Interstellar Flight and Intelligence in the Universe. Spaceflight, v. 14, December 1972: 442.

[40] In Walter Sullivan, We Are Not Alone, New York, McGraw-Hill, 1966, p. 238.

[41] Shklovskii and Sagan, op. cit., p. 446.

c. *Matter-Antimatter.*—This is the most theoretical of the systems, for antimatter has never really been seen, only its effects have. It is the opposite of matter, so that when the two meet they annihilate each other (as positrons and electrons do) and release energy, usually in the form of gamma rays. For this reason, antimatter is uncommon on Earth, or there would be no Earth, as the following poem illustrates (Dr. Edward Teller was the first to envision antimatter):

Well up beyond the tropostrata
  There is a region stark and stellar
Where, on a streak of anti-matter
  Lived Dr. Edward Anti-Teller.

Remote from Fusion's origin
  He lived unguessed and unawares
With all his anti-kith and kin,
  And kept macassars on his chairs.

One morning, idling by the sea,
  He spied a tin of monstrous girth
That bore three letters: A.E.C.
  Out stepped a visitor from Earth.

Then, shouting gladly o'er the sands,
  Met two who in their alien ways
Were like as lentils. Their right hands
  Clasped, and the rest was gamma rays.[42]

It is just this violent reaction that makes a matter-antimatter combination such an excellent propellant, for the exhaust velocity would be very close to *c*. Purcell calculates that the mass ratio would be merely 14, although that would be only for one-quarter of the trip since the ship must start up, slow down when it reaches another planet, start up again to head home, and stop once more. This makes the ratio 14^4 or 40,000 (which is still better than a billion for fusion). Thus for a 10 ton payload, the rocket would have to weigh 400,000 tons, half matter and half antimatter.[43] Another complicating factor is that since antimatter and matter annihilate each other, the former could not be held in a container made from any substance. Sagan has recommended a "nonmaterial, magnetic bottle, employing an intense magnetic field."[44]

2. The human factor

Once the propulsion debate is solved, there still remains the factor of the short lifetime of homo sapiens. Journeys to other worlds could take thousands of years—our average life span is about 70.

Three methods of dealing with this are discussed below, although other scenarios, such as generation ships, are conceivable. The first two, hibernation and suspended animation, are closely related in that they both involve slowing the metabolic rate. Hibernation, however, implies a natural process, while suspended animation is induced by external

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[42] H. P. Furth, Perils of Modern Living. In R. L. Weber. A Random Walk in Science, New York. Crane, Russak & Co., 1973, p. 65. Reprinted with permission. Copyright 1956, The New Yorker Magazine, Inc.
[43] Purcell, op. cit., p. 137.
[44] Shklovskii and Sagan, op. cit., p. 445.

sources. The third option, relativistic travel, is more related to propulsion systems, since the spaceship's speed must be very close to *c* for the physical laws to apply.

a. Hibernation.—Biologists have long wondered what it is that tells groundhogs when to begin hibernating in winter and when to awaken in spring, for if they could tap that enzyme, chemical, gene or whatever, they might be able to apply it to other species, including man.

Hibernation, unlike sleep, is a process in which all unnecessary bodily functions are discontinued, for example, growth. The animal's body temperature remains about 1° above the temperature of its environment. During this period, animals appear to be immune to disease and if subjected to a lethal dose of radiation, the animal will not die until the hibernation period is over. (As a point of interest, bears do not hibernate, they only sleep more deeply in winter.)

Early in this century, Dr. Max Rubner proposed that aging was a result of the amount of energy expended in tissues. "Rubner found that the total lifetime energy expenditure per gram of tissue during the adult stage is roughly constant for several species of domestic animals. 'The higher the metabolism, the shorter the life span and vice versa.' " [45]

In this vein, scientists found that the storage of body fat was vital to a hibernating animal's survival: it loses 20–40 percent of its body weight while dormant. The body fat involved here is called "brown fat" and differs structurally from normal, white fat cells and has a greater heat producing potential. A low temperature signals the brown fat to increase in temperature, which warms the animal's blood and spreads the warmth to other parts of the body. Newborn human infants have an unusually high percentage of brown fat which diminishes as they grow older. Adults do have some brown fat, and those with underproductive thyroid glands have more than normal:

> Rats subjected to cold temperatures show an increased ratio of brown fat to white fat. It seems reasonable to expect that cold acclimation in man, through a carefully controlled program of cyclic hypothermia [see below], will increase brown fat deposits. After these deposits reach a certain body level, they might perform the same regulatory functions in human hibernation that brown fat performs in natural hibernators.[46]

About ten years after Rubner's experiments, Drs. Jacques Loeb and John Northrop discovered that reduced temperatures extended the life span of fruit flies. In applying this to animals, however, those that were not natural hibernators or who had not been prepared for hibernation, developed ventricular fibrillations (where the heart muscle quivers and stops pumping blood). When a person "freezes to death" this is the cause, not ice crystals forming in the veins.

The process involved in artificially cooling an animal's body temperature is called induced hypothermia. Research in this field led space biologist Dale L. Carpenter (McDonnell Douglas, Long Beach) to determine that both hibernating and non-hibernating animals have

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[45] Robert W. Prehoda, Suspended Animation, Philadelphia, Chilton Books, 1969, p. 28.
[46] Ibid., p. 35.

the same basic temperature control and he believes that "were a non-hibernating mammal to be artifically biochemically prepared with proper enzymes and energy producing chemicals, it could hibernate." [47] He found that if an animal was cooled just until its heart began quivering and then rewarmed, it could survive. If cooled a second time, a slightly lower temperature could be achieved before ventricular fibrillations occurred, and so on. Each exposure to the cold seemed to condition the heart to accept lower temperatures. This is cyclic hypothermia.

Even with this kind of progress, however, the search goes on for the chemical or enzyme that triggers the hibernation process, that tells the animals it is winter or spring. Scientists hope to gain some insight into this mystery from human infants, who in addition to having more brown fat than adults, seem less susceptible to ventricular fibrillations. They have different forms of hemoglobin and myoglobin in their tissues which are more efficient in attracting and releasing oxygen. This may hold the clue.

If hibernation could be induced in humans, this could solve the problem of interstellar travel. One would not have to worry about travelling near *c*, for the crew would not age as fast and would have more time to reach their destination. Maxwell Hunter suggests that this "biological time dilation" be applied not only to the crews, but to those that remain on Earth.

> We are thus faced with the prospect of a whole society dilated in time. This would form the basis for a Galactic Club which was based on travel rather than communication. * * *
>
> We are not talking about timefaring in the classic science fiction sense where people are able to go both backward and forward in time at will. * * * We are postulating, rather, dilating the time experienced by people in one direction in the future * * * which would permit a society to expand throughout the galaxy. If, when one went to bed at night, he actually went into hibernation during which many months passed, it would not seem any different to him than a standard eight-hour sleep. * * * When a ship returned home, its crew would be greeted by friends, business colleagues, etc., who had aged no more than the crew. * * * [48]

b. Suspended animation.—Induced hypothermia can be taken one step further to the point where an organism is actually frozen but can later be revived. This is suspended animation or cryogenic preservation. Although the words suggest a futuristic, science fiction scenario, successful experiments have already been performed in this field. Most research to date has been with cells, and blood, semen, viruses and many other microorganisms can now routinely be put in suspended animation and brought back unharmed.

The National Academy of Science held a round table conference in 1975 to examine the state-of-the-art and prospects for the future. In

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[47] Ibid., p. 31.
[48] Maxwell Hunter II, In a speed at Foothill College, San Francisco, July 12, 1975.

the introduction to the conference's proceedings, Dr. Bernard LaSalle stated:

> Through cryogenic preservation, it may be possible to indefinitely stop biological time, stop aging, halt all the life processes of bacterial and animal cells, and return them to full life activities at any point in time.
>
> Complete plants have been produced from single cells. If this can be done with animal cells, it may be possible to produce identical tissues and organs in unlimited numbers. It is refreshing to think that through applied cryobiology the world may be improved.[49]

A very important application of this technology would be in agriculture, where some genetic characteristics are gradually being bred out of cattle. Someday these characteristics may be needed again, but once they are bred out, there is no hope of regaining them. If the cells of certain strains were cryogenically preserved, however, specimens of the same type could be produced when the need arises.

The first successful use of this technique brought to life the first "frozen bull" in June 1973. Twenty-two calf embryos were taken from their natural mothers after ten days of pregnancy and frozen to −196° C at the rate of 0.2° C per minute. An antifreeze agent (dimethylsulphoxide) was used to replace some of the water in the cells to prevent ice forming, much as antifreeze is added to a car's radiator in winter.

The eggs were kept frozen for six days and then thawed in a 37° C water bath at a rate of 360° C per minute and then transplanted into a host uterus. Only one of the eggs survived the cryogenic process and development in the uterus, but that one bull was born apparently unscathed from its experience.[50]

In relating this to humans, one major problem to overcome is possible cell damage that may occur during the freeze-thaw cycle. Ice is less dense than water and occupies a larger volume (which is why a glass of water will break if left in a freezer too long), and a cell could rupture. The antifreeze method employed with the calf embryo might have limited usefulness in a human adult, for death could occur from poisoning due to the large amount needed. Also, there are areas deep inside an adult where heat and cold are not transferred uniformly. For this technique to be successful, the body must be frozen uniformly and quickly (and unfrozen in the same manner). Because of their smaller size, infants do not have the internal areas where heat is transferred differently, nor would as much dimethylsulphoxide be needed, so tests would probably begin on them. The legal, moral and ethical issues involved in such experimentation would have to be solved first, of course.

Once the technology is available, spaceship crews could be placed into suspended animation indefinitely. A device aboard the ship could be programmed to detect when the ship had reached its destination, or if problems arose, and administer adrenaline into the veins

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[49] U.S. National Committee for the International Institute of Refrigeration. Round Table Conference on the Cryogenic Preservation of Cell Cultures, Washington, D.C., National Academy of Sciences, 1975: viii.

[50] For a more detailed account see: Bullseye, Nature, v. 243, June 25, 1973: 371.

of the ship's commander. She could then determine if the other members of the crew should be awakened.

c. Relativistic travel.—The theory of relativity, in addition to determining that matter reaches infinite mass as it reaches *c*, shows that a clock on a speeding spaceship runs slower than one on a stationary home base. This can be shown as

$$T = T_0\sqrt{1-\left(\frac{v}{c}\right)^2}$$

where T is the time on the spaceship, T_0 the time on the home base, *v* is velocity, and c is speed of light.

Following this formula, von Hoerner derived a table showing times required for interstellar travel at 1 g (the maximum amount of acceleration he suggests man can withstand for a period of years), as depicted in figure 4–13.

FIGURE 4-13*

TOTAL DURATION AND DISTANCE REACHED WITH CONSTANT ACCELERATION AND DECELERATION AT 1G

Duration (out and back), years		
For crew on board rocket	For people on earth	Distance reached, parsec
1	1.0	0.018
2	2.1	.075
5	6.5	.52
10	24	3.0
15	80	11.4
20	270	42
25	910	140
30	3,100	480
40	36,000	5,400
50	420,000	64,000
60	5,000,000	760,000

* von Hoerner, Sebastian. The General Limits of Space Travel. Science, v. 137, July 16, 1962: 18-23. Reprinted with permission. Copyright 1962 by American Association for Advancement of Science.

With relativistic travel, then, man could not only reach the center of our galaxy within a human lifetime (which is the most densely populated area), but to other galaxies as well.

The theory has already been demonstrated with a subatomic particle called muon (or mu meson). A muon on Earth has a very short lifetime, 2.2 millionths of a second, yet those that are part of cosmic rays and are generated at the top of the atmosphere survive long

Their time is slower then ours and therefore their lifetimes, relative to us, are prolonged. The same could conceivably happen to a human.

> Aboard a relativistic interstellar space ship, not only would the passengers' clocks move more slowly than their counterparts on Earth, but they themselves would move more slowly, their hearts would beat more slowly, their awareness of the passage of time would be retarded.[51]

[51] Shklovskii and Sagan, op. cit., p. 442.

CHAPTER FIVE

CHARACTERISTICS OF INTELLIGENT EXTRATERRESTRIAL LIFE

Having discussed the possibility of intelligent life existing on other planets in the universe and methods to locate and communicate with it, the next question is what type of beings we might expect to find. Will they be warlike or peaceful? Tyrannical or benevolent? Look like a homo sapien or a crocodile?

A. Physical Characteristics

1. Biological

Even through the imaginations of the most respected science fiction writers, aliens tend to have many of the same physical characteristics as humans. They may be shorter or taller, have swollen heads or extra appendages, but they still stand erect, have arms and legs, speak through something similar to a mouth and see through eyes. Considering the apparent random chance aspects of our own evolution, this approach seems somewhat chauvinistic. Why, on a planet with more or less gravity than Earth, ammonia instead of water, and hotter or cooler temperatures, would creatures be expected to resemble Earth inhabitants in any way?

Roger McGowan and Frederick Ordway III, in their discussion of what they expect aliens to look like, exemplify this chauvinism:

> Most intelligent extrasolar land animals will quite probably be approximately the same order of magnitude in physical size as humans. There is a rough correlation between brain size and body size. * * * An animal must have a sufficiently large body to support a large brain. * * * Perhaps intelligent extrasolar animals may range upwards to as much as ten times the size of humans. Greater sizes would require enormous energy supplies for locomotion, creating an effective upper size limit.[1]

In a separate publication, Ordway expanded on this by describing the alien's biology. Again predicting that the animal would have to be large enough to survive the evolutionary period and to have a brain, yet small enough not to have to spend a great deal of time simply eating and finding food, he states:

> . . . we may expect their central nervous system to be rather close to the main sensory organs and brain * * * a high position, such as a head seems logical, to provide the being with good vision and an excellent location from which to communicate with fellow beings. * * * They must be

[1] Roger MacGowan and Frederick Ordway III, Intelligence in the Universe, New Jersey, Prentice-Hall, 1966, pp. 240–241.

> mobile and hence will have limbs on which they can maneuver about—perhaps two legs or perhaps four. * * * They will have appendages, permitting them to manipulate things. We call our hands and have two; other beings may have more, probably in even numbers. For symmetry and balance, an odd number is unlikely.[2]

Why aliens could not communicate from a position nearer the ground than a head is unclear, as is the argument about needing limbs for maneuvering—snakes seems to manage quite well without arms or legs.

MacGowan and Ordway also discuss the possibility of marine or airborne intelligence, but consider it unlikely, saying that marine life is less likely to have manipulative skills and airborne animals consume so much energy in flying, they would require vast amounts of food. Those authors do not discuss, however, why a species such as octopus could not develop manipulative skills with tentacles, or how surface and air conditions could be different and evolve other types of airborne creatures.

A more imaginative description of neighboring aliens is provided by Ronald Bracewell. He suggests that if a planet had three times the gravity of Earth, for example, lizard-like creatures might hold the advantage.

> Instead of an arboreal ancestry, such creatures may have found their antecedents in swamps, where gravity could be counteracted by buoyancy and then, instead of taking to the plains and becoming upright walkers, as our ancestors did, they might have moved out from their place of genesis along waterways, natural and artificial.[3]

Dr. Bracewell goes even further, envisioning a race of "intelligent scum" which could exist in colonies with close cooperation and specialization. Comparing the colony to the human brain, a "convoluted assembly of cells distributed in layers," he foresees the scum rolling themselves into a ball and acquiring a protective coating. "In the course of time, the cells on duty at the mouth of the bag might be the only ones to retain sensitivity to light. These sentry cells would be evolving toward eyes."[4] The opposite of this type of colony of unicellular organisms would be Fred Hoyle's black cloud (see chapter 2), a single organism of great size.

To demonstrate the many possibilities of life forms on planets with different conditions from Earth, Bonnie Dalzell of the Smithsonian Institution drew a series of pictures which are shown in Appendix D.

2. Artificial intelligence

Another possibility is that we may encounter mechanical life. As discussed in chapter 2, the lifetime of a civilization (L) is a determining factor in the equation for the number of extant civilizations in the galaxy (N). Another race may decide to develop automated replicas or representatives of themselves to carry on after their civilization becomes extinct. Or automata could be developed as servants of a

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[2] Frederick Ordway III. Life in Other Solar Systems. New York, E. P. Dutton, 1965, p. 86.

[3] Ronald Bracewell, The Galactic Club, Stanford, Calif., Stanford Alumni Association, 1974, p. 86.

[4] Ibid., p. 87.

biological race and advance to the point where they no longer need their progenitors and journey out into space creating civilizations of their own. Both of these conditions would increase the value of *N*.

MacGowan and Ordway give this subject extensive treatment. They describe several facets of our own biology that could be improved when creating mechanical life, for example, seeing and hearing. In the visual range, we need eyeglasses, telescopes and microscopes to assist our vision. Automata could be produced with a flexible optical arrangement incorporating these features and resulting in a greater range of sight. Similarly in hearing, more sensitive receivers could be installed, much as we use hearing aids. Along with these improved senses would be improved processing ability: "Unquestionably, the most important aspect of automaton design is the capability and capacity of the central processing unit." [5]

The two authors list a series of advantages automata would have over biological life. Memory banks could be programmed with information that would take a lifetime for a biological specimen to acquire. Maintainability is another positive factor, for the automata should be able to exist indefinitely with only minor repairs.

> A more impressive attribute * * * would be the control of their own growth. Not only would it be possible for an automaton to direct the production of its own replacement parts, but it could also design and produce additional components for its own growth. * * *
>
> An automaton could easily control its own evolution as well as its growth by gradually incorporating new technological development. New technology could be incorporated by removing one major module at a time and either replacing it with a more advanced module, or modifying it so as to assimilate the new technology.[6]

They conclude that "most" societies that Earth might communicate with would probably be directed by automata. With unlimited life spans and "astronomical intellectual potential" they would also be more likely candidates for interstellar travel, according to MacGowan and Ordway.

B. Sociological Characteristics and Possible Consequences of Contact

Any discussion of what social attitudes aliens might have or their intentions toward Earth is as speculative as describing their physical characteristics, since we have only ourselves as an example. Since their history is apt to be vastly different from ours, we are unlikely to have very much in common.

> Most obvious and basic of the cultural and political factors is the inevitable difference of historical experience. The alien's cultural frame of reference, codes of behavior, and styles of social interaction will be different from ours. Only at the most basic and generalized level are we likely to be on common ground (a concern for one's own security being an example).[7]

[5] MacGowan and Ordway, op. cit., p. 226.
[6] Ibid., p. 232.
[7] Michael Michaud, Interstellar Negotiation, Foreign Service Journal, v. 49, December 1972: 12.

A popular argument is that any civilization advanced enough to travel in interstellar space will also be advanced enough to transcend petty differences and nationalistic rivalries. Whether or not they are peaceful in their own society, however, may not reflect on how they would act toward another race. For example, prior experience may have taught them to travel through space prepared for military action precipitated by the the beings they find, as demonstrated in the science fiction film classic, *The Day the Earth Stood Still.*

The consequences of making contact with another civilization is a subject with widely varying opinions. It seems equally plausible that an alien race would either want to conquer Earth and use it for some undeterminable purpose, or to have a peaceful, mutually beneficial relationship. There is no way to make a definitive judgment on an issue such as this, so the following excerpts are provided to form a basis for discussion.

> Thus, Philip Morrison, in one of his lectures, questioned whether any civilization with a superior technology would wish to do harm to one that has just entered the community of intelligence. If he were looking through a microscope, he said, and saw a group of bacteria spell out, like a college band, "Please do not put iodine on this plate. We want to talk to you," his first inclination, he said, would certainly not be to rush the bacteria into a sterilizer.[8]
>
> —Philip Morrison is a Physicist at MIT.

> Aliens from other solar systems are a potential threat to us, and we are a potential threat to them. Scientists and others have often postulated that extraterrestrial societies more advanced than ours would be less warlike. Regrettably, the stereotype of the benevolent, superintelligent alien may be as unrealistic as the stereotype of bug-eyed monsters carrying off shapely human females. Even if a species had achieved true peace within its own ranks, it would still be worried about us, and would take the measures it felt were necessary to protect itself. This includes the possibility (not the inevitability) of military action. . . .
>
> Our basic interest will be to protect ourselves from any possible threat to Earth's security. Our second concern would be to assist in developing—or to participate in—a stable system of interstellar politics that provides an acceptable level of security for all. Our third concern would be to learn from the aliens in order to advance our knowledge of the universe and to add to the tools of civilization. The last interest, so often placed first by writers on this subject, would be meaningless or impossible if the first two concerns had not been satisfied.[9]
>
> —Michael Michaud, U.S. State Department.

> Therefore, the only immediate effect on human society of the establishment of communications with extrasolar communities would be the sudden acquisition of a vast amount of

[8] Walter Sullivan, We Are Not Alone, New York, McGraw-Hill, 1966, pp. 279–280.
[9] Michael Michaud, Negotiating with Other Worlds, The Futurist, v. 7, April 1973 : 74.

Although all these factors are vitally important and need to be taken into account when deciding on how vigorously to pursue a program of interstellar communication, one must remember that our presence could now be detected out to 50 light years (see chapter 4). The decision is, then, whether to sit passively by and wait for others to find us, or whether we should take the initiative. The Soviet Union, at least, seems to have opted for the latter.

A 1960 report for the National Aeronautics and Space Administration studied the possible consequences of contact and suggested its own research directions:

> Anthropological files contain many examples of societies, sure of their places in the universe, which have disintegrated when they have had to associate with previously unfamiliar societies espousing different ideas and different life ways. * * *
>
> Since intelligent life might be discovered at any time * * * two research areas can be recommended:
>
> 1. Continuing studies to determine emotional and intellectual understanding and attitudes—and successive alterations of them if any—regarding the possibility and consequences of discovering intelligent extraterrestrial life.
>
> 2. Historical and empirical studies of the behavior of peoples and their leaders when confronted with dramatic and unfamiliar events or social pressures. * * * [15]

Considering reactions people have had to UFO's and Orson Welles' reading of *War of the Worlds* over the radio, such advice seems sound.

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[15] Sullivan, op. cit., pp. 278–279.

APPENDIX A

Conclusions of the NASA Interstellar Communications Study Group[1]

First Conclusion

IT IS BOTH TIMELY AND FEASIBLE TO BEGIN A SERIOUS SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE

Only a few decades ago most astronomers believed that planetary systems were extremely rare, that the solar system and the habitat for life that Earth provides might well be unique in the Galaxy. At the same time so little was known about the chemical basis for the origin of life that this event appeared to many to verge on the miraculous. No serious program for detecting extraterrestrial intelligence (ETI) could arise in such an intellectual climate. Since then numerous advances in a number of apparently diverse sciences have eroded the reasons for expecting planetary systems and biogenesis on suitable planets to be unlikely. Indeed, theory today suggests that planetary systems may be the rule around solar type stars, and that the Universe, far from being barren, may be teeming with life, much of it highly evolved.

During the latter half of the last and the first part of this century the slow rotation of the Sun stood as a formidable objection to the nebular hypothesis of Kant and Laplace, which proposed that planetary systems formed out of the same condensing cloud that produced the primary star. An initial rotation rapid enough to produce the Sun's planets should have produced a Sun spinning a thousand times faster—too fast to become a spherical star. As a result, various "catastrophic" theories of the origin of the solar system were proposed, all of which depended on events so rare as to make the solar system virtually unique.

Then, in the late 1930's, Spitzer showed that starstuff torn out by tidal or concussive forces would explode into space rather than condense into planets. Shortly thereafter research into plasma physics, and observations of solar prominences, revealed the magnetohydrodynamic coupling of ionized matter to magnetic fields, a mechanism whereby stars in the process of formation can slow their rotation. As a result, the theory in which planets condense out of the whirling lens of gas and dust that will become a star has regained wide acceptance. Planetary systems are now believed to exist around a substantial fraction of stars.

Meanwhile the discoveries that the organic building blocks for DNA and proteins can be formed by natural processes out of molecules comprising the early atmosphere of Earth, and that many organic molecules are even formed in the depths of interstellar space, have made the spontaneous origin of life on suitable planets seem far more probable. Life appears to have developed on Earth almost as soon as seas had formed and chemical evolution had provided the building blocks. Earth has been lifeless for only a small fraction of its age. This leads many exobiologists today to look upon life as a very likely development, given a suitable planet.

The present climate of belief makes it timely to consider a search for extraterrestrial life, but is such a search feasible? It is certainly out of the question, at our present level of technology or, indeed, at any level we can foresee, to mount an interstellar search by spaceship. On the other hand, we believe it is feasible to begin a search for signals radiated by other civilizations having technologies at least as advanced as ours. We can expect, with considerable confidence, that such signals will consist of electromagnetic waves; no other known particle approaches the photon in ease of generation, direction and detection. None flies faster, none has less energy and is therefore cheaper than the radio frequency photon. It has long been argued that signals of extraterrestrial origin will be most apt to be detected in the so-called microwave window: wavelengths from about 0.5 to 30

[1] NASA, SETI: Search for Extraterrestrial Intelligence, NASA SP 419 [prepublication issuance] Moffett Field, Calif., NASA, 1977, pp. 13–35.

cm. Natural noise sources rise to great height on either side of this window making it the quietest part of the spectrum for everyone in the Galaxy. We concur with these arguments.

Existing radio telescopes are capable of receiving signals from our interstellar neighbors, if of high power or if beamed at us by similar telescopes used as transmitters. The large antenna at Arecibo could detect its counterpart thousands of light years away. Indeed, it could detect transmissions from nearby stars less powerful but similar to our own television and radars.

Terrestrial UHF and microwave emanations now fill a sphere some twenty light years in radius. This unintended announcement of our technological prowess is growing stronger each year and is expanding into space at the speed of light. The same phenomenon may well denote the presence of any technological society. In fact, our own radar leakage may have already been detected by a nearby civilization. In addition, advanced societies may radiate beacons for a variety of reasons, possibly merely to bring emerging societies into contact with a long established intelligent community of advanced societies throughout the Galaxy. A search begun today could detect signals of either type.

We propose a search for signals in the microwave part of the radio spectrum, but not at this time the sending of signals. Even though we expect our society to continue to radiate TV and radar signals we do not propose to increase our detectability by, say, intentionally beaming signals at likely stars. There is an immediate payoff if we receive a signal; transmission requires that we wait out the round trip light time before we can hope for any results. Transmission should be considered only in response to a received signal or after a prolonged listening program has failed to detect any signals.

Not only is the technology for discovering ETI already at hand, but every passing year will see the radio frequency interference (RFI) problem grow worse while only modest improvements in technology can occur. Perfect receivers would not double the sensitivity of a search system over that which we can already achieve. Given optimum data processing, large increases in sensitivity are to be had only by increasing collecting area. It is true that data processing technology is improving rapidly, but presently achievable data processing technology is adequate and inexpensive. Further, the techniques need to be developed in association with existing facilities and comprehensive searches made before it becomes evident that a more sensitive system is needed. Great discoveries are often the result more of courage and determination than of the ultimate in equipment. The Nina, the Pinta, and the Santa Maria were not jet airliners, but they did the job.

Second Conclusion

A SIGNIFICANT SETI PROGRAM WITH SUBSTANTIAL POTENTIAL SECONDARY BENEFITS CAN BE UNDERTAKEN WITH ONLY MODEST RESOURCES

A large, expensive system is not now needed for SETI. If we but equip existing radio telescopes with low-cost state-of-the-art receiving and data processing devices, we will have both the sensitivity to explore the vicinity of nearby stars for transmitters similar to Earth's, and to explore the entire Galaxy for more powerful signals, or for signals beamed at us. Such explorations, even should they yield negative results, would decrease our uncertainty concerning whether intelligent life transmitting powerful signals may lie beyond our solar system. At the very least, it would be of great interest and some importance either to know we have near neighbors, or to be reasonably confident no nearby transmitting civilizations exist. If, *after* we have made such modest searches, it seems important to us to embark upon a more ambitious SETI program, such as contemplated by the Cyclops study, the experience we will have gained will prove not only invaluable, but essential. Moreover, we expect to derive spin-off benefits of no small significance.

SETI Hardware

The arguments for electromagnetic waves as the communications medium seem compelling. The case for the microwave window seems very strong. The reasons for preferring the low end of the window are also strong, but not so strong that higher frequencies in the window should be ignored. The "water hole" between the H and OH lines is an especially attractive band that may be ideal for long range beacons.

ETI signals, particularly those intended for detection by other searching societies, will probably be narrow in bandwidth compared with natural sources

and may have monochromatic components which are as narrow as the interstellar medium permits. This increases their detectability of a given radiated power and distinguishes them from the natural background. The hardware needed for SETI therefore consists of an antenna or antenna system, low-noise wide-band receivers to cover the low-frequency end of the microwave window, means of resolving the received spectrum to a very high degree and means to search out and identify automatically any spectral anomalies.

Since halving the system noise temperature is equivalent to doubling the system sensitivity, it is important in SETI to have the lowest noise receivers that can be built. The background temperature in the preferred frequency region is only 6 K to 8 K (3 to 5 K in space) so every degree of reduction in receiver noise temperature is significant. The development of suitable low noise receivers represents a simple extension of present microwave technology and is not an expensive program. It would also benefit deep space communications and radio astronomy.

To search for narrow band signals that may be anywhere in a wide frequency band and to do so in a reasonable time has been one of the major challenges of a SETI. In the Cyclops system concept the received signal was optically transformed into a high-resolution power spectrum. Since 1971 the growth of large-scale integrated circuit technology has been spectacular. It now appears possible to build, at reasonable cost, solid state fast Fourier analyzers capable of resolving the instantaneous bandwith into at least a million channels on a real time basis. Development of such equipment is again a modest undertaking and the equipment would be very valuable for many other uses besides SETI.

To complete the data processing it is necessary to examine the power spectrum or a succession of samples of the power spectrum for any sort of significant pattern such as a sustained peak that may drift slowly in frequency, a regularly recurring peak, or arrays of regularly spaced peaks, to name but a few. The data rates are so great that this pattern recognition must be automated. The principal problems associated with the pattern recognition system are the amount of data storage needed and the identification of the types of patterns to be recognized. Only a few years ago these could have presented severe difficulties, but the solid state electronics revolution has so reduced the cost of memory, that prospective data processing costs appears to be relatively inexpensive.

It has been estimated that the development of the right data processing equipment would increase the capability of existing radio telescopes to detect ETI signals by about a thousandfold. This means that very significant searches can be made using existing antennas so equipped and it is recommended that the search begin in this way. The possibility of discovering some unknown type of natural source in this way must not be overlooked.

Search strategies

It is not feasible to search for all kinds of signals at all frequencies from all directions to the lowest flux levels at which a known signal of known frequency and direction of arrival can be detected. The more inclusive the search becomes in frequency or spatial direction, the more time is required, unless we sacrifice sensitivity. This is, of course, the reason for making use of all available *a priori* information and guesses as to preferred frequencies and likely directions of arrival. Many ingenious arguments have been offered for special frequencies and directions or even times; all can be given some weight as the search proceeds. On the other hand, every reduction in some dimension of the search is based on an assumption that may be wrong.

The strategy of searching nearby F, G, and K main sequence stars at ever increasing range seems very natual; the only life we know lives on a planet around a G2 dwarf star. This strategy takes us only as far into space as necessary to discover our nearest radiative neighbors around such stars. On the other hand, only slightly older cultures may be capable of radiating much more powerful signals, or they may know that life is to be found only around a few stars of a certain spectral class and age and may beam signals at these. As is true for stars, the nearest transmitters may not be the brightest. The strongest signals may come from advanced societies at great distances, whose transmitters may not even be near any stars.

For these reasons it is premature to adopt only one strategy to the exclusion of others. To cover a wide range of other possibilities it is recommended that in addition to a high sensitivity search of nearby stars, there also be a complete search of the sky to as low a flux level and over as wide a frequency band as practicable.

To be significant a full sky survey should be able to detect coherent radiation at a flux level one or two orders of magnitude below that provided by existing radio astronomy surveys. This turns out to be easier than one might expect. Although a sky survey as sensitive as $\sim 3 \times 10^{-23}$ W/m^2 has been made this has covered only ~2 percent of the sky. Another, covering most of the sky, has been made to a sensitivity of $\sim 2 \times 10^{-20}$ W/m^2. But in these, as apparently in all radio astronomy sky surveys, any coherent signals that might have been present were rejected as "interference." Thus a complete sky survey using SETI data processing equipment to detect coherent signals at flux levels of $\sim 10^{-20}$ to $\sim 10^{-24}$ W/m^2 would be very significant. Existing antennas could be used to search the water hole to this level and the entire microwave window to as low as $\sim 10^{-23}$ W/m^2 in a few years of observing time.

The target search of the nearer F, G, and K main sequence stars should be conducted using SETI hardware with existing antennas. This would permit detection of coherent signals at a flux level as low as $\sim 10^{-27}$ W/m^2, or 10^3 to 10^7 times weaker than for the full sky search, assuming an observation time on the order of a half hour per star.

Both the sky survey and the targeted search could produce positive results, but even negative results will be of value since the upper limit flux levels that would result will be much lower than before. This could change our assessment of the capabilities of other intelligent life. The experience gained using SETI hardware in actual operation, with natural and man-made interference present, will affect the design of any future search strategies, and may lead to modifications of hardware, software, and search procedure. The searches we propose can be completed in approximately five years.

Planning a dedicated facility

SETI is more than a single effort. Like the exploration of the New World by our forefathers, like the present exploration of our solar system, it should be accomplished by many missions, each with some particular goal in mind. But there is a limit to the time that can be reasonably devoted to SETI from the facilities of radio astronomy or other serviecs. To achieve the ultimate goals of SETI it will probably be important to have a dedicated SETI facility, the planning for which should begin now. This facility may never need to grow beyond a collecting area equivalent to one, or a few 100 meter dishes. That will depend on future priorities, and on what we learn from the searches we immediately propose. The facility may be on the ground, or in space. We should, however, keep possible future needs in mind, and be prepared to build it whenever and wherever it appears appropriate.

Supporting activities

Several ancillary programs should be initiated and pursued. These include protection of the water hole (1.400 to 1.727 GHz.) against radio frequency interference (RFI), the detection of extrasolar planetary systems, the development of techniques for compiling extensive lists of target stars, the study of alternative search strategies, and the continuing study of the cost effectiveness of space vs. ground based systems.

In a resolution adopted at its fourth meeting the Science Workshop recommended that that international protection of the water hole against RFI be sought at the 1979 World Administrative Radio Conference. Navigational satellite systems are presently being planned that would destroy the usefulness of this prime band of frequencies for SETI purposes. It is important to realize that for ground based SETI systems such protection does not exclude all other services from the water hole, but only interfering ones such as satellites and nearby ground services. The RFI problem for space based SETI systems (especially systems in synchronous orbit) is more complex and probably more serious. Adequate shielding may be very expensive. It is not necessary that RFI protection of the water hole continue for all time. If no signals are found after a protracted sensitive search, the SETI priority may be relinquished.

The *sine qua non* of SETI is the plenitude of other planetary systems. While theoretical considerations suggest that planetary systems are common, it would be valuable to know *how* common and how their achitecture varies with stellar class and multiplicity. Earlier astrometric telescopes and data reduction techniques could be improved to the point where the existence of near-by planets could be proved or disproved, but the effort might require two or three periods of a major planet, i.e., two or three decades. Preliminary calculations indicate that the direct

observation of major planets around nearby stars should be possible with space telescopes of only modest size (on the order of one meter diameter). This could be accomplished by fitting the space telescope with a suitable filter or mask which greatly improves the contrast of a large planet with respect to the central star. Such an approach, if successful, would permit planets to be found in only two to three years after launch. This and other space techniques for direct planetary detection deserve active study and support.

Present star catalogues list the coordinates of F, G, and K main sequence stars within only a few tens of light years of the Sun. If we ultimately carry on a search out to several hundred light years we will need to know the location of a thousand times as many target stars as are now listed. The problem of how best to conduct a whole sky star classification and cataloging program needs to be studied and, when solved, to be implemented. Since the compilation of such a target star data base must precede a major search, it is timely to begin the design study now. Both a greatly expanded catalogue of the solar neighborhood and knowledge about nearby planetary systems would be significant contributions to galactic and stellar astronomy as well as to SETI.

Although it is assumed that the searches performed in this program will be mainly for narrow band signals at the low end of the microwave window, other possibilities should not be ignored. Given a matched filter a series of pulses is just as easy to detect as a CW signal of the same average power. The pulsed signal, however, introduces the new dimensions of pulse shape, repetition rate, and duty cycle. At this time it is not clear that CW signals are more probable than pulses. Continuing study of these and other alternatives is indicated.

It will be seen that the program advocated above is of modest scale yet has potential for both SETI success and scientific contribution. Above all it serves as a logical introduction to the future but does not constitute a blank check commitment to a large expensive effort. The program is not a dead end nor is it open ended. It will be timely to consider whether to proceed with a larger scale program after this earlier effort has shown us more accurately what might be involved.

Third Conclusion

LARGE SYSTEMS OF GREAT CAPABILITY CAN BE BUILT IF NEEDED

Large systems, involving construction of new antennas, are not now needed for SETI. Until we have completed an observational program as suggested in the Second Conclusion, there seems to be no reason to construct any facility much larger in scale than Areçibo. However, we may some day decide to embark on a more comprehensive search. This could require a system of great capability. Although we emphasize that we do not now recommend construction of such a system, we also feel that it is important to emphasize that a large SETI system is well within the capability of present-day technology.

The first feasibility study of large SETI systems was the 1971 Cyclops project. It concluded that we indeed have the technology to construct a very large ground-based phased array. The system considered would be capable of operating over the 1 to 10 GHz region of the microwave window, and could grow to collecting areas of many square kilometers if necessary. Its receiving system would be coupled to a data processing system capable of resolving 200 MHz of spectrum into 0.1 Hz channels and of detecting any coherent signal whose power equalled the noise power in this 0.1 Hz bandwidth.

At the request of the Ames Interstellar Communication Study Group, the Jet Propulsion Laboratory performed a detailed independent review of the Project Cyclops report, and found the study to be correct in its major technological conclusions. Today the data reduction would probably use large scale integrated circuit hardware exclusively, rather than optical processors. Today the system noise temperature could be nearer 10 K than 20 K. But these improvements only reinforce the basic conclusion that ground based systems can be built that will detect a gigawatt *omnidirectional* beacon or its equivalent at a distance of 1,000 light years. This corresponds, in the water hole, to a flux of one photon per second per square kilometer.

The principal cost of the Cyclops system was found to be the antennas. If the effectiveness of the data processing could be improved enough to double the sensitivity for the same antenna area, the original system performance could be achieved at about half the cost. Clearly in systems having large collecting area it is very important to make optimum use of that area by doing the best

possible job of data processing. Further studies of the coherent signal detection problem and the possible tradeoffs in time and money vs antenna area are needed and should be started now.

Ground based vs space systems

Following the Cyclops study the Interstellar Communication Study Group at Ames contracted with the Stanford Research Institute to study various alternatives to a ground based array in achieving large collecting area. A dozen alternatives were considered, four ground based, four lunar based, and four in space.

The study revealed that very large, very lightweight, single unit antennas in space may be cost competitive with a large ground based array. This conclusion can only be stated as a possibility and not as a fact because of the obvious difficulty of making valid cost comparisons between the well understood, mature ground based antenna technology and the poorly understood, untested technology of large, lightweight space antennas.

In addition to the primary feasibility and cost of the space structures many other problems associated with space systems need further study. These include how to shield the receiver against the severe RFI expected in space, the provision for wide band data links on a continuous basis, the logistics of servicing and maintaining and operating a complex system in space. However, space systems also give unique advantage with respect to system noise, sky and frequency and tracking ability. All that can be said at present is that space systems must be carefully considered in future plans.

Obviously, the whole question of Earth versus space based systems needs an order of magnitude more study before the issue can be resolved; this must be done before a commitment is made to any large search system. The possibility exists that a combination of ground and space systems would offer advantages not to be found in either alone.

Intermediate steps

As discussed in the second conclusion, a small dedicated facility for SETI will probably eventually be desirable. This will most likely be a single new ground-based, or small-based, antenna of advanced design, or both. If the facility is ground-based, it would be prudent if its site and design are chosen to ensure that the system be expandable at least to an intermediate size, such as a small array of 6 to 18 antennas. Such a system would increase the sensitivity well beyond that achievable with any existing antenna and would permit simultaneous searches using different strategies. It would also allow phasing techniques to be tested.

With respect to space borne antennas, it may be desirable, as studies proceed, to fly one or more medium size designs as shuttle payloads. The missions should be designed not only to test the structures but also to allow actual SETI and radio astronomy observations to be made in space. These antennas in conjunction with a dedicated ground facility could be used together as a very long baseline interferometer of greater capability than any now employed in radio astronomy. In addition observations could be made throughout the wide frequency bands over which the atmosphere is noisy or opaque.

Scientific applications

As soon as a dedicated SETI facility achieves either a sensitivity or special coverage not found in present radio or radar astronomy instruments, it becomes a uniquely useful tool for research in these areas. An almost continuously increasing spectrum of applications exists as the SETI facility is expanded in scope. It is recommended that a fraction of the time of any dedicated facility be devoted to scientific research which that facility alone makes possible. This might well provide a series of discoveries which in themselves help justify the cost of the SETI facility.

We see that either in space or on the ground the SETI effort can effectively grow from the initial effort to one using a very large system at whatever rate is appropriate. Early studies are needed to refine concepts of large systems, and especially to evaluate the usefulness of space. Even in the absence of the discovery of ETI signals, useful discoveries in science will accrue as the facility expands.

Fourth Conclusion

SETI IS INTRINSICALLY AN INTERNATIONAL ENDEAVOR IN WHICH THE UNITED STATES CAN TAKE A LEAD

The Search for Extraterrestrial Intelligence offers benefits for all nations. The search would certainly be facilitated by, and may even require, international cooperation. It is a serious exploration, as important as any ever undertaken, and surely of larger scope than the journeys to the Earth's poles early in the century. We can hope for relatively quick results, but must prudently prepare for a protracted effort. The program must be kept open and public in the spirit of international science and exploration. We can and should expect growing cooperation with investigators from many countries, both those already displaying interest and activity, as the Soviet Union and Canada, and others whose interest would grow.

SETI is not only a response to the spirit of exploration but is natural to the metaphysical view of modern man. The question "Are we alone?" is pertinent to the entire species, both to us and our descendants.

International cooperation is essential to solving the radio frequency interference problem discussed above. Furthermore, it is possible that antennas may be required at various places throughout the world or in space: a system beyond the borders of any single nation. It seems clear to us that the SETI effort should be cast as a cooperative international endeavor at the start and that appropriate international relationships should be established through existing or novel international organizational arrangements. Joint funding is a desirable goal for such an approach. In any case the extended period which may be required for the detection of extraterrestrial intelligence—much less communication—emphasizes the need for organizational and cultural support more enduring than typically characteristic of national programs.

There may be a particular opportunity for joint Soviet and U.S. efforts in the SETI. The Soviets have already begun a preliminary search. Their published discussion of this problem indicates that considerable interest exists within the scientific community there. The USSR is capable of substantial space technology should that prove important in the future. Finally, joint leadership of an international SETI program by the U.S. and the Soviet Union might constitute a logical continuation of the cooperative endeavors in space initiated by the Keldysh-Low agreements most recently responsible for the Apollo-Soyuz Test Program.

West European nations, especially West Germany, Holland, and England, have also evidenced increasing interest in new radio astronomical endeavors. Thus, the possibility of initiating a SETI program through bilateral or multilateral arrangements involving the U.S. warrant consideration as well.

The United States can lead in the SETI endeavor

The United States has frequently demonstrated the will and foresight to take the initiative in programs of worldwide benefit. The U.S. space program has provided not only excitement and scientific knowledge, but numerous practical satellite services not alone for this country, but for the whole world. It is in this same spirit of providing a focal point for international cooperation and support that we feel the U.S. can and should take the initiative in SETI.

The material, technological and intellectual resources of the U.S. are such that a large-scale SETI program could be carried on indefinitely by this country alone without appreciable drain on the economy. There are good reasons for believing the net effect on the economy could be positive. Even if international cooperation and support were slow to materialize, we believe SETI remains a feasible and worthwhile U.S. endeavor.

The psychology of and mechanisms for international cooperation suggest that an international SETI effort is unlikely until one big nation, such as the U.S., seizes the initiative and invites serious participation by others. It is in this sense of initiative and and not in the pursuit of narrow national advantage that we recommend a leading role for the U.S. in SETI.

Initiating the SETI effort

To carry on a significant United States SETI effort, public funds must be committed explicity, with the approval of both the legislative and executive branches of the Federal Government. The evolution of an appropriate federal program lies with Congress and the President, but can only follow much preparatory work supported by one or more existing agencies.

We recognize that successful administration of the SETI program will require leadership by an agency with:

a. a mandate to carry out scientific research and exploration, possibly requiring operations in space;

b. large scale project management experience;

c. the ability to successfully involve the U.S. and foreign scientific community in a large scale enterprise;

d. in-house expertise in the relevant fields of technology; and

e. long range goals compatible with SETI.

Since NASA clearly meets these criteria it is particularly appropriate for NASA to take the lead in the early activities of a SETI program. SETI is an exploration of the Cosmos, clearly within the intent of legislation that established NASA in 1958. SETI overlaps and is synergistic with long term NASA programs in space astronomy, exobiology, deep space communications and planetary science. NASA is qualified technically, administratively and practically to develop a national SETI strategy based on thoughtful interaction both with the scientific community and beyond to broader constituencies.

We therefore recommend that NASA continue its pioneering initiative in studying and planning near-term activities in support of SETI, and we urge that NASA, in cooperation with other agencies, begin the implementation of SETI.

APPENDIX B

SOVIET ASTRONOMY, 18(5) MARCH–APRIL 1975

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CONFERENCE REPORTS—THE CETI PROGRAM

In March 1974 the Board of the Scientific Council on the Radio Astronomy Problem Area, Academy of Sciences of the USSR, considered and approved a Research Program on the Problem of Communication with Extraterrestrial Civilizations. The Program was developed by the Search for Cosmic Signals of Artificial Origin section of the Council on Radio Astronomy, on the basis of recommendations made at the Soviet National Conference on the Problem of Communication with Extraterrestrial Civilizations held at the Byurakan Astrophysical Observatory in Armenia in May 1964, and the Soviet-American CETI conference held at Byurakan in September 1971. The projected program was reported to the 7th Soviet National Conference on Radio Astronomy, which convened at Gor'kii in 1972.

The program as outlined below is here published in detail with minor abridgments.

RESEARCH PROGRAM ON THE PROBLEM OF COMMUNICATION WITH EXTRATERRESTRIAL CIVILIZATIONS

PART I. INTRODUCTION

1. Formulation of the Problem
2. Principal Fields of Research on the Problem of Extraterrestrial Civilizations
3. Principles for Developing a CETI Program
4. Organizing Arrangements

PART II. SEARCH FOR COSMIC SIGNALS OF ARTIFICIAL ORIGIN

1. Search for Sources and Selection by Preliminary Criteria
    - 1.1 Radio Surveys of the Sky
    - 1.2. Selection of Sources by Angular Size and Investigation of Their Spatial structure
    - 1.3. Investigation of Selected Galactic and Extragalactic Objects
    - 1.4. Search for Signals from Stars in the Immediate Solar Neighborhood
    - 1.5. Search for Signals From Galaxies in the Local Group
    - 1.6. Search for Signals With a Detection System Covering the Entire Sky
    - 1.7. Search for Probes
    - 1.8. Measurement of Cosmic Background Radiation in the Wavelength Range 20μ—1 mm
    - 1.9. Investigation of Absorption and Phase Transparency of the Interstellar Medium in the Range 20μ—1 cm
    - 1.10. Sky Surveys in the Range 10μ—1 mm
    - 1.11. Search for Infrared Excesses in Stars of Suitable Spectral Type
2. Investigation of the Radiation Structure of the Selected Objects and Methods of Analysis for Identifying Sources Suspected of Being Artificial
3. Instrumentation Projects for Seeking Radio Signals From Extraterrestrial Civilizations

PART III. DECODING OF SIGNALS

PART IV. CONCLUSION

PART I. INTRODUCTION

1. FORMULATION OF THE PROBLEM

Over the past few years the scientific community has begun to show increasing interest in the problem of contacts with extraterrestrial civilizations.

The question of whether intelligent life exists elsewhere in the universe in some form or another has been posed in every era throughout the development of science. Yet it is only now, thanks to major advances in astronomy, biology, cybernetics, information theory, radiophysics and radio engineering, and the conquest of space, that it has become possible for the first time to progress from purely speculative arguments on this subject to systematic scientific investigation. The achievements of modern science have led to a deeper understanding of the fundamental aspects of the problem. The hope of establishing communication with extraterrestrial civilizations today rests on a scientific basis. This endeavor has come to be called the CETI problem (Communication with Extraterrestrial Intelligence).

Advances in radiophysics and radio engineering have played a decisive role here. Modern radio techniques would enable signals transmitted across interstellar distances to be detected and recorded. Thus it is already feasible to plan research and experiments for detecting signals from extraterrestrial civilizations. From the very outset such investigations can and should rest on the achievements of radio astronomy, in which much experience has now been gained in identifying and analyzing sources of cosmic radio emission. Progress in infrared and optical astronomy will also make a vital contribution, in conjunction with rapidly advancing developments in laser technology. Also of great value for the practical organization of a CETI program will be the achievements of information theory and other branches of cybernetics, which offer general methods for studying problems of information transfer, as well as such areas of mathematics as game theory, the theory of tactics, and searching theory. With these disciplines as a basis a special CETI strategy can be devised. At the present time, then, the technical ways and means are available for practical steps to be taken in the CETI field.

The possibilities of radio communication with extraterrestrial civilizations were first analyzed by G. Cocconi and P. Morrison (United States, 1959), who showed that under certain conditions signals could be received from extraterrestrial civilizations with the radio technology available at that time. In 1960 the first practical steps were taken in the United States to look for such signals at 21-cm wavelength (F. D. Drake, Project Ozma). At present a more comprehensive signal search program is under way at the U.S. National Radio Astronomy Observatory (Project Ozma 2), and a Project Cyclops has been studied[1] by Stanford University in collaboration with the Hewlett-Packard Company: it would ultimately cost tens of billions of dollars. In the Soviet Union, work comparable to Project Ozma is being carried out at the Gor'kii Radiophysics Institute.

These projects presuppose that extraterrestrial civilizations have a level of technological development analogous to our own. In this event one would anticipate discovery of monochromatic radiation similar to the radiation from ordinary transmitters on the earth.

In 1964 another signal search concept was put forward in the Soviet Union, whereby extraterrestrial civilizations would be expected to have a very high level of development. Several radio-astronomical criteria for an artificial source were formulated on the basis of this concept. Experiments were subsequently devised at the Shternberg Astronomical Institute of Moscow University and at the Institute for Space Research, Academy of Sciences of the USSR, for the purpose of examining a number of peculiar sources in order to see whether they might satisfy the proposed criteria.

Searches for pulsed signals from space have recently been undertaken in the Soviet Union at the Gor'kii Radiophysics Institute, the Institute for Space Research, and the Shternberg Astronomical Institute. Various aspects of the CETI problem are being studied individually not only at these institutions, but by the Council on Radio Astronomy of the Academy of Sciences of the USSR, the Moscow Power Institute, the All-Union Electrical Engineering Correspondence

Institute of Communications, the Russian Language Institute, Academy of Sciences of the USSR, and elsewhere.

One other approach, entailing a search for signs of astro-engineering activity by highly developed extraterrestrial civilizations (in particular, from surveys of infrared radiation), has been suggested by F. J. Dyson (U.S.).

In 1960, R. N. Bracewell (U.S.) made the important suggestion that a search ought to be conducted for radio signals from space probes, which even now might conceivably be present in the solar system.

The U.S. National Academy of Sciences held a special conference in 1962 on the problem of communication with extraterrestrial civilizations.

Major contributions toward formulating and discussing the CETI problem have been made by the Soviet National Conference on the Problem of Communication with Extraterrestrial Civilizations [2] (Byurakan, 1964) and the Soviet-American CETI conference [3] (Byurakan, 1971). Topics pertaining to the CETI problem [4] have been considered at various other conferences and meetings both in the Soviet Union and abroad.

The present program has been developed from recommendations by the 1964 Soviet National Conference, the 1971 International Conference, and the 7th Soviet National Conference on Radio Astronomy in 1972.

2. PRINCIPAL FIELDS OF RESEARCH ON THE PROBLEM OF EXTRATERRESTRIAL CIVILIZATION

The problem of extraterrestrial civilizations comprises an intricate complex of topics in philosophy and sociology as well as nature science. Within the domain of this broad interdisciplinary problem a narrower area is to be considered: the CETI problem. This represents a separate task confronting science and technology, including theoretical and experimental work on searching for extraterrestrial civilizations, as well as modeling the basic links in the CETI system. But a successful result will depend on resolving a number of fundamental questions that form the heart of the extraterrestrial-civilization problem.

It is convenient to distinguish two groups of problems for planning the investigations.

Group A. Fundamental Problems of Extraterrestrial Civilizations Involving Communication

1. Astronomical matters.—Cosmogony. Discovery of planets, planetlike bodies, and congealed stars. Sky surveys conducted in various parts of the electromagnetic spectrum. Examination of some peculiar sources. Investigation of organic compounds in cosmic objects.

2. Life.—A more precise definition of the concept of "life." Possible existence of nonprotein life forms. Origin of life on the earth; possible alternative origins of life on other cosmic bodies, and in interplanetary and interstellar space. Exobiology. Laws of biological evolution and their exobiological generalization.

3. Intelligence and intelligent systems.—Refinement of the concept of "intelligence" or "reasoning." Models of an intelligent system. Theory of complex self-organizing system. Information contacts in complex systems. Symbolic systems; language. Problems in the theories of knowledge and reflection; construction of models.

4. Mankind.—Analysis of the laws governing the development of civilization on the earth. Special characteristics of the rise and development of different civilizations worldwide. Forecasting. Development and mastery of the space environment.

5. Information transfer.—Optimum methods of communicating information.

These topics are being dealt with independently of the CETI problem itself and therefore are not considered in the present program (except for the sky surveys).

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[2] G. M. Tovmasyan, ed., Extraterrestrial Civilization (Proc. Byurkan conf., May 1964), Armenian Acad. Sci. Press (1965) [Israel Program Sci. Transl., No. 823 (1967)].

[3] C. Sagan, ed., Communication With Extraterrestrial Intelligence (CETI) (Proc. Byurakan conf., September 1971), MIT Press (1973).

[4] S. A. Kaplan, ed., Extraterrestrial Civilizations: Problems of Interstellar Communication, Nanka, Moscow (1969) [NASA TT F-631 (1971)].

Group B. Problems Pertaining Directly to CETI

1. *Aspects of the theory of cosmic civilizations.*

2. *Contacts between cosmic civilizations; possible types of contact and their consequences.*

3. *Modes of intercourse between cosmic civilizations.*—Linguistic media to be devised for establishing information contact between "intelligent" systems.

4. *Procedures and scientific technological basis for seeking signals from extraterrestrial civilizations.*—Development of signal search techniques. Influence of the cosmic medium on exchange of signals between civilizations. Choice of optimum electromagnetic wavelength range. Criteria for identifying signals from extraterrestrial civilizations. Characteristics of "call letters." Design of search instrumentation. Modeling of individual links in the CETI system. Computer modeling.

5. *Searches for signals from extraterrestrial civilizations.*

6. *Deciphering of signals.*

7. *Searches for astro-engineering activity of extraterrestrial civilizations.*—Although the main emphasis in this program is given to efforts to find signals in the radio range and to the development of suitable techniques and equipment, a more complete program should also include planning with regard to other aspects of the CETI problem.

3. PRINCIPLES FOR DEVELOPING A CETI PROGRAM

The present program has been drawn up on the basis of the following initial propositions.

1. Efforts to detect extraterrestrial civilizations should proceed smoothly and systematically, and should extend over a prolonged period of time. The program is oriented in this direction from the very outset. It would be a great mistake to build a program in contemplation of rapid and easy success.

2. Investigations should be based on a specially devised program (or group of programs) which would be revised and perfected as time passes. The program should provide every opportunity to take advantage of existing technology (radio telescopes, antenna systems and associated instrumentation), and should also envision the development of specialized techniques and equipment for coping with the CETI problems.

3. The program will recognize that astrophysical information will be acquired as a byproduct of the search for signals from extraterrestrial civilizations. When actual investigations are undertaken it will be necessary to analyze carefully the question of what astrophysical applications can be pursued during search activities.

4. In view of the uncertainty in our a priori knowledge as to the character of signals from extraterrestrial civilizations, the program should entail parallel studies in several directions.

4. ORGANIZING ARRANGEMENTS

1. Matters relating directly to CETI (Group B) are currently being worked on in a random fashion; such research is not being planned properly.

But the problem has now reached a state requiring more earnest organizational efforts. If the research is to proceed successfully one cannot avoid creating a number of organizations and institutions to deal with appropriate branches of the problem; these should be fully staffed and furnished with equipment and materials. The design of search instrumentation and detection systems calls for organizational enterprise on an industrial scale. Henceforth all scientific and engineering work in the field of searches for signals from extraterrestrial civilizations ought to be placed under the guidance of a pilot organization.

2. Matters pertaining to Group A topics are being pursued independently of the CETI problem, and often quite separately from one another. In the very near future thought should be given to ways in which these studies can be coordinated and purposefully integrated into the CETI plane.

PART II. SEARCH FOR COSMIC SIGNALS OF ARTIFICIAL ORIGIN

INITIAL PREMISES

The program for seeking signals from other civilizations rests on the two assumptions mentioned above as to their level of development:

1. A level of technological development and, in particular, the technology of

2. A level of technological development and modes of communication far more advanced than our own.

For the first case, from considerations of power capability, signals should be sought primarily from nearby stars. The character of the signals might be analogous to the signals of transmitters on the earth; that is, narrowband signals may be anticipated (it would then be possible to generate special call signals distributed over a wide frequency range so as to facilitate searches with respect to frequency).

In the second case the detection problem would be considerably simpler because of the much greater power capacity. However, uncertainty might arise both in the coordinates of the source (as such civilizations would not necessarily be associated with stars) and in the character of the signal. Presumably the signals of highly developed extraterrestrial civilizations would most likely be wideband. Although this circumstance would ease the search in frequency, it would require the formulation of definite criteria enabling such signals to be distinguished from wide-band radiation of natural origin. Regions that might be worth searching could be located near the nuclei of our own and other galaxies, or associated with certain peculiar sources.

This program presupposes the need for parallel research at both the levels 1 and 2 above with no priori assumptions as to the character of the signals. Thus the problem of methodically searching for signals from extraterrestrial civilizations will include the following aspects: (a) a search for sources of radiation with respect to direction, frequency, and time; (b) an analysis of the structural properties of the radiation; (c) determination of its artificial nature.

Accordingly, this program provides for the following steps in research activity:

1. Search for and selection of sources according to preliminary criteria.
2. Examination of the radiation structure of the sources selected.
3. Analysis of the results obtained, in an effort to identify artificial sources.

1. SEARCH FOR SOURCES AND SELECTION BY PRELIMINARY CRITERIA

This step entails both conducting sky surveys in the optimum wavelength range from the CETI standpoint followed by source selection according to preliminary criteria, and analysis of sources already known. The result should be the compilation of a catalog of objects promising from the CETI standpoint and warranting further study in more detail.

As criteria for preliminary source selection, the following may be used and are adopted in this program: small angular size; distinctive spatial structure of the source; distinctive spectrum (special behavior of the energy distribution, presence of narrow-band features, special shapes in the spectrum such as rectangular features, and so on); unusual character of time variability; distinctive polarization properties (such as a regular alternation of left- and right-circular polarization in the spectrum). As astrophysics progresses and new data emerge, this list could be refined or revised.

1.1. Radio Surveys of the Sky

Frequencies.—Since a CETI signal might be restricted in its spectrum, in order to discriminate promising sources the surveys should fully cover the entire short-wave portion of the radio-astronomy range (frequencies of 1–100 GHz), which according to present indications is the most advantageous region for CETI purposes.

In the initial phase surveys could be made at discrete frequencies for which appropriate instrumentation is already available or is under development.

Antennas.—The principal antennas for conducting surveys in the USSR could be the RATAN–600 (the periscopic part) in the wavelength range 0.8–21 cm, and the antenna for the millimeter range being developed at the Gor'kii Radio-physics Institute.

Instrumentation.—Radio receiving equipment for the surveys should include:

1. Continuum radiometers with $\Delta f \sim 0.1f$ and $T_n \sim 100°K$, equipped with facilities for magnetic-tape recording and with auxiliary output devices for the detection of information-carrying signals according to anticipated criteria.
2. Radiometric systems with as wide a band as possible ($\Delta f \sim 0.5f$).
3. Spectral radiometers for surveys at the frequencies of individual radio lines, such as $\lambda\lambda$ 21, 18, and 1.35 cm.

1.2. Selection of Sources by Angular Size and Investigation of Their Spatial Structure

a. Preliminary selection of sources with an angular size smaller than the antenna beam, and investigation of their spatial structure. No specialized equipment would be required.

b. Measurement of the angular (as well as the linear) size and spatial structure of sources by the interstellar-scintillation technique. This method affords the highest angular resolution. However, for surveys at wavelengths shorter than 10 cm. or in the case of very close sources ($R<10$ pc) the interferometer method is best. The radio telescopes may either be ground-based or stationed in space, permitting earth–earth, earth–space, and space–space baselines.

1.3 Investigation of Selected Galactic and Extragalactic Objects

On the basis of astrophysical evidence presently available, studies of the following objects would be of interest from the CETI standpoint: globular clusters, representing the oldest objects in our galaxy; the galactic center, a region containing 10^9 stars; the galaxies of the Local Group; certain nearby radio galaxies and quasars.

The aim of such investigations would be to discover anomalies in the radio emissions of these objects from the point of view of the criteria given above.

Instrumentation.—Antennas with an effective area greater than 1000 m² should be used for most of the objects. It is recommended that the size, spatial structure, and radio variability be investigated by the scintilation technique with earth-earth, earth-space, and space-space baselines, using a radio telescope in space and others on the ground. Spectroscopic and polarimetric properties could be examined with the same equipment and with the RATAN–600 radio telescope.

This type of work is closely linked with the central problems of radio astronomy and can be carried out in the course of conventional radio-astronomical research.

1.4 Search for Signals from Stars in the Immediate Solar Neighborhood

It is proposed that individual nonvariable stars of suitable spectral type be observed. Initially the observations may be confined to monitoring all appropriate stars to a distance of 10–100 light years from the sun; eventually out to 1000 light years.

If the monitoring extends over a period of several years, then in order to inspect all suitable stars within a radius of 100 light years with a single antenna operating continuously, the total observing time for each star would be about one hour, or no more than a few hours.

Antennas.—For this survey it would be desirable to use several radio telescopes with an effective area of $\sim$ 1000 m². Observations could begin with smaller sized telescopes.

The primary task in the initial phase of investigation would be to detect radio emission from stars, because the intrinsic radio emission of solar-type stars is weak. As for the kind of signals to be expected, it would be advisable to begin by searching for very simple signals—pulsed, monochromatic, and the like. This program will impose corresponding requirements on the instrumentation.

In the future one might hope to search for signals by sending automated space probes to the nearest stars.

1.5 Search for Signals from Galaxies in the Local Group

Any search for signals from galaxies would enable an enormous number of stars (roughly 10^{10}–10^{11}) to be covered simultaneously. The nearest galaxies are of interest to us inasmuch as we might be of interest to them.

Since the number of objects is small, a continuous monitoring service could be organized, with observations extending over several years. The optimum wavelength range for each object can be made more definite by taking its background into consideration.

Antennas.—For a continuous service, weakly directional antennas would be used with a beam covering the galaxy being observed ($\theta\sim1$–$3°$). In addition, it would be desirable to employ larger antennas with an effective area of $\sim$1000 m² so that parts of galaxies could be investigated and repeated surveys made of each galaxy.

Instrumentation would be similar to that used for pulsed signals (if they have a low averaged power not influencing the observed flux density of the galaxy, they could still have a high peak power, ensuring that $P_s/P_n>1$) as well as monochromatic signals.

In studying galaxies with the aim of detecting signals from extraterrestrial civilizations, one will no doubt acquire information of astrophysical character pertaining to those galaxies.

1.6 Search for Signals with a Detection System Covering the Entire Sky

The detection system would here be designed for continual monitoring of the radiation of the whole sky in the optimum anticipated wavelength range. Such a system would enable transient sporadic signals coming from any direction to be recorded.

Regular monitoring of the entire sky would require a network of stations located at different points on the globe or in space.

For stations placed on the earth, the number needed is determined by the condition that objects be simultaneously visible from at least two widely spaced stations (in order to discriminate local interference), so that at least four would be required altogether.

If stations are placed in space at a large distance from the earth, just two would be sufficient. The best plan would evidently be to put these stations in orbit around the moon, because when they pass behind the moon maximum suppression of terrestrial interference would be assured. One very promising location for a space station would be the Lagrangian point in the earth-moon system located beyond the moon.

Building a system of large directional radio telescopes to cover the whole sky would be a major undertaking financially. Thus at the outset we would propose that investigations be organized with nearly omnidirectional antennas that would record only the strongest signals. Subsequently the stations would be equipped with high-efficiency antennas, and the detection capability of the system could be raised gradually.

Frequencies.—In due course the entire shortwave part of the radio-astronomy range should be examined. At present the search should be limited to discrete frequencies, using equipment now available or under development.

The main effort at first should be concentrated toward searches for sporadic pulsed signals. It would be advisable to begin this program by utilizing equipment that satisfies the following requirements:

The recording system should detect pulses lasting from 1 sec to 10^{-8} sec (with a choice of time constants differing by decade factors).

The equipment should be provided with a system for obtaining the dispersion measure for an approximate distance estimate of a source, and for discriminating terrestrial interference.

Observations should be controlled by the Time Service to a precision adequate for these measurements. A rough determination of the direction toward a source could be made from the lag in the signals at different stations.

Restrictions on the observing stations.—The principal requirement is a low noise level. Such stations will generally be located in regions difficult of access. Perhaps a full suppression of interference and elimination of the effects of the earth's atmosphere, as well as a more accurate determination of positions, will demand that some of the stations (at least two) be placed in space at large distance from the earth.

1.7. Search for Probes

The possible discovery of probes sent from extraterrestrial civilizations and now located in the solar system or even in orbit around the earth warrants particular attention. To search for these rapidly moving objects the system of constant monitoring of the whole sky should be supplemented by specialty designed radio direction-finding systems. Initially it would be possible to use existing installations intended for space communications and radar observations.

1.8. Measurement of Cosmic Background Radiation in the Wavelength Range 20μ — 1 mm

Such measurements are needed to identify regions of minimum intensity and establish more accurately the optimum wavelength range for CETI purposes.

1.9. Investigation of Absorption and Phase Transparency of the Interstellar Medium in the Range 20μ — 1 mm

1.10. Sky surveys in the Range 10 — 1 mm

These surveys should be made in an effort to find objects associated with the engineering activity of extraterrestrial civilizations.

It is proposed that the sky be surveyed in this wave-length range and that

1.11. Search for Infrared Excesses in Stars of Suitable Spectral Type

The purpose of this search would be to detect thermal radiation inherently emanating from large-scale works of engineering that may have been constructed in circumstellar space.

Telescopes and equipment for surveys 1.10 and 1.11—A special mountain observatory should be built (so as to diminish losses of infrared radiation due to absorption by atmospheric water vapor) with a telescope about 2.5–3 m in diameter, and a specialized satellite carrying analogous instrumentation should be launched.

The receivers would be high-sensitivity bolometers with a selection of filters.

2. INVESTIGATION OF THE RADIATION STRUCTURE OF THE SELECTED OBJECTS AND METHODS OF ANALYSIS FOR IDENTIFYING SOURCES SUSPECTED OF BEING ARTIFICIAL

Each of the objects selected by the preliminary criteria will be investigated more carefully, and the research program will be modified in each instance depending on the results of the measurements obtained during the preliminary selection process.

It would be desirable to conduct the analysis of cosmic radio waves along the following lines: examination of the shape of the radio spectrum as a whole for envelopes and carrier waves; inspection of the fine structure of the spectrum; recordings of rapid variability of the carrier and envelope spectra; establishment of the carrier and envelope distribution functions; determination of how the polarization (especially circular polarization) depends on the carrier frequency and on time; investigation of recordings obtained by analog and digital detection of carriers and envelopes at different frequencies and bands for both.

The data obtained in this manner would be used to identify sources suspected of being artificial. The methods and criteria for identification should include an analysis of all data from the standpoint both of astrophysics (comparison with known and possible natural astrophysical objects) and cybernetics and information theory (comparison of the statistical properties and structure of the signal with known or anticipated types of communication).

3. INSTRUMENTATION PROJECTS FOR SEEKING RADIO SIGNALS FROM EXTRATERRESTRIAL CIVILIZATIONS

To ensure that the avenues of research described above will be carried out, two instrumentation projects, CETI 1 and CETI 2, are proposed, as follows:

CETI 1 Project (1975–1985)

1. A ground-based system continuously monitoring the entire sky, comprising eight stations with nondirectional antennas supported by detection equipment capable of covering the whole optimum wavelength range.
2. A satellite system continuously monitoring the entire sky, comprising two space stations with nondirectional antennas and fully covering the optimum wavelength range.
3. A system of low-directivity antennas of 1–3 beamwidth for a continuous survey of nearby galaxies (subsection 1.5). These antennas might conveniently be located at the same stations where the sky is continuously monitored by nondirectional antennas.

CETI 2 Project (1980–1990)

1. A satellite system continuously monitoring the entire sky and equipped with antennas of large effective area.
2. A system of two widely spaced stations having large (effective area ~ km²) semirotatable antennas for synchronized reception, searches for signals from specific objects, and analysis of selected sources.

These instruments complexes could be used not only for CETI work but for a variety of important astrophysical problems.

In addition, individual parts of the program could be carried out with other radio telescopes in conjunction with the plans of radio-astronomy institutions (sky surveys, investigations of peculiar sources, and so on).

PART III. DECODING OF SIGNALS

One of the most important problems in need of solution for CETI purposes is to work out deciphering techniques specifically applicable to extraterrestrial communications (in the absence of any a priori information as to the language,

method of encoding, and character of the signals). Within the present program a leading role should be assigned to logically formal deciphering techniques, comprising algorithms that can be implemented only by computer, and enabling a given linguistic entity to be designated according to a maximum of special "estimator" functions computed from counts made on the text being analzed. The decoding procedure for signals from extraterrestrial civilizations that is to be developed as part of this program may be broken down into several steps.

1. *Preliminary analysis of signals.*—In this step the alphabet of the elementary signals (messages) would be established.

2. *Determination of type of text language organization.*—Three types of organization are presumably possible: pictorial (image transmission), linguistic (analogous to the structure of languages on the earth), and formalized (as with logical computer languages or algorithms).

3. *Disclosure of grammatical system of the language.*—The properties of the test explained by the internal structure of the language would be ascertained at this stage, that is, the parametrization of the frames and alphabetic gradations used to express model languages. The grammar of a humanoid language would be determined, or for formalized systems, the axioms and rules of construction and derivation.

4. *Disclosure of the semantics of texts under investigation.*

5. *Development of methods for translating the decoded language into familiar languages.*—This step would, in particular, encompass techniques for automatic compilation of bilingual dictionaries and structural correspondence lexicons.

The development of signal decoding techniques is closely related to research on image recognition, automatic classification and encoding (for example, some of the algorithms worked out in the decipherment analysis might be applied to study the structure of branches of the national economy), and work in the area of computer translation and automated abstracting.

Part IV. Conclusion

Even in their initial stage investigations of the CETI problem can be of important cognitive and applied value, and can serve as a source of useful information and a stimulus in many fields of science and technology.

This working program, which includes experimental and theoretical projects of immediate concern, is provisionally directed toward the next 10–15 years. It should form part of a more complete program taking the long view, and it also offers a basis for developing specialized, detailed programs in particular areas of research that fall within the scope of the CETI problem.

Continual revision and improvement should be made in the program as data are accumulated in all fields pertaining to CETI and as individual search programs are conducted.

APPENDIX C

CONTENTS OF VOYAGER RECORD [1]

Pictures (in electronic form).
President Carter's message (in electronic form).
Congressional list.
U.N. Secretary General Waldheim's message (spoken).
Greetings in 60 languages.
Sounds of **Earth.**
Music.

LANGUAGES HEARD ON VOYAGER RECORD

(Not In Sequential Order)

Sumerian	Bengali	Mandarin
Akkadian	Urdu	Gujorati
Hittite	Hindi	Ila (Zambia)
Hebrew	Vietnamese	Nyanja
Aramaic	Sinhalese	Swedish
English	Greek	Ukrainian
Portuguese	Latin	Persian
Cantonese	Japanese	Serbian
Russian	Punjabi	Luganada
Thai	Turkish	Amoy (Min dialect)
Arabic	Welsh	Marathi
Roumanian	Italian	Kannada
French	Nguni	Telugu
Burmese	Sotho	Oriya
Spanish	Wu	Hungarian
Indonesian	Korean	Czech
Kechua	Armenian	Rajasthani
Dutch	Polish	
German	Netali	

SOUNDS OF EARTH ON VOYAGER

(In Order of Sequence)

Whales	Footsteps and Heartbeats	Horse and Cart
Planets (Music)	Laughter	Horse and Carriage
Volcanoes	Fire	Train Whistle
Mud Pots	Tools	Tractor
Rain	Dogs, domestic	Truck
Surf	Herding sheep	Auto gears
Crickets, Frogs	Blacksmith shop	Jet
Birds	Sawing	Lift-off Saturn 5 Rocket
Hyena	Tractor	Kiss
Elephant	Riveter	Baby
Chimpanzee	Morse Code	Life signs—EEG, EKG
Wild Dog	Ships	Pulsar

COPY OF PRESIDENT'S MESSAGE PLACED ON VOYAGER RECORD

This Voyager spacecraft was constructed by the United States of America. We are a community of 240 million human beings among the more than 4 billion who inhabit the planet Earth. We human beings are still divided into nation states, but these states are rapidly becoming a single global civilization.

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[1] NASA Press Release 77–159, Aug. 1, 1977.

We cast this message into the cosmos. It is likely to survive a billion years into our future, when our civilization is profoundly altered and the surface of the Earth may be vastly changed. Of the 200 billion stars in the Milky Way galaxy, some—perhaps many—may have inhabited planets and spacefaring civilizations. If one such civilization intercepts Voyager and can understand these recorded contents, here is our message:

"This is a present from a small distant world, a token of our sounds, our science, our images, our music, our thoughts and our feelings. We are attempting to survive our time so we may live into yours. We hope someday, having solved the problems we face, to join a community of galactic civilizations. This record represents our hope and our determination, and our good will in a vast and awesome universe."

JIMMY CARTER,
President of the United States of America.

The WHITE HOUSE,
June 16, 1977.

VOYAGER MESSAGE OF U.N. SECRETARY GENERAL

As the Secretary General of the United Nations, an organization of 147 member states who represent almost all of the human inhabitants of the planet Earth, I send greetings on behalf of the people of our planet. We step out of our solar system into the universe seeking only peace and friendship, to teach if we are called upon, to be taught if we are fortunate. We know full well that our planet and all its inhabitants are but a small part of the immense universe that surrounds us and it is with humility and hope that we take this step.

KURT WALDHEIM.

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Music on Voyager Phonograph Record

(In Sequential Order)

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3. Senegalese Percussion, recorded by Charles Duvelle.
4. Pygmy girls initiation song, recorded by Colin Turnbull (Zaire).
5. Australian Horn and Totem song. Recorded in Australia by Sandra LeBurn Holmes. Barnumbirr-Morning Star Record.
6. "El Cascabel" Lorenzo Barcelata. The Mariachi Mexico.
7. "Johnny B. Goode", Chuck Berry.
8. New Guinea Men's House, recorded by Robert MacLennan.
9. "Depicting the Cranes in Their Nest" recorded by Coro Yamaguchi (Shakubachi).
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11. Mozart Magic Flute, Queen of the Night (Aria Number 14) Edda Moser, soprano.
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13. Peruvian Pan Pipes performed by Jose Maria Arguedas.
14. Melancholy Blues performed by Louis Armstrong. Columbia Records.
15. Azerbaijan Two Flutes. Recorded by Radio Moscow.
16. Stravinsky, Rite of Spring, Conclusion. Igor Stravinsky conducting the Columbia Symphony Orchestra.
17. Bach Prelude and Fuque, Number One in C Major from the Well Tempered Clavier, Book Two, Glenn Gould, piano.
18. Beethoven's Fifth Symphony, First Movement. Otto Klem Klemperer conducting. Angel Recording.
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20. Navajo Indian Night Chant. Recorded by Williard Rhodes.
21. The Fairie Round from Pavans, Galliards, Almains. Recorded by David Munrow.
22. Melanesian Pan Pipes. From the collection of the Solomon Islands Broadcasting Service.
23. Peruvian Women's Wedding Song. Recorded in Peru by John Cohen.
24. "Flowing Streams"—Chinese Ch'in music. Performed by Kuan P'ing-Hu.
25. "Jaat Kahan Ho"—Indian Raga. Performed by Surshri Kesar Bai Kerkar.
26. "Dark Was the Night" performed by Blind Willie Johnson.
27. Beethoven String Quartet Number 13 "Cavatina", performed by Budapest String Quartet.

APPENDIX D

[From the Smithsonian Magazine, October 1974. Reprinted with permission, copyright 1974 by Smithsonian Institution.]

Exotic Bestiary for Vicarious Space Voyagers

(By Bonnie Dalzell)

To be put in charge of evolution on nine planets is a task no self-respecting biologist could shirk. So when the Smithsonian's National Air and Space Museum needed someone to design life-forms for the Pick-a-Planet exhibit in its newly opened hall, Life in the Universe, I leaped at the chance.

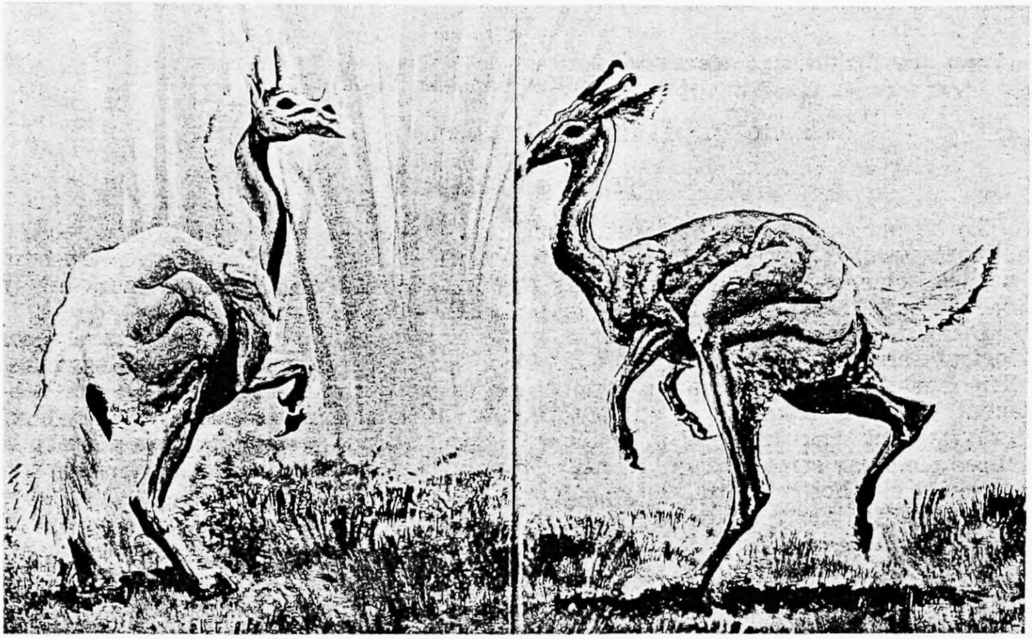
Designing unearthly animals is a game anyone can play but there are some logical rules—the same ones that apply on Earth theoretically apply elsewhere. The most basic rule is that life evolves in response to the nature of the environment. One major feature of our environment is something we rarely think about gravity. But what kinds of animals would you find on a planet where gravity is three times as strong as on Earth? Or only two-thirds as strong? What if the planet were hotter overall? Or colder? Wetter or drier? By combining these variables, we arrived at nine imaginary planets, and for each one I designed three animals—terrestrial, aquatic and aerial. What follows are some of my candidates for an interstellar zoo.

The pair of biped antelope are from a low-gravity, temperate planet. Each has a mass equivalent to a donkey on Earth (about 600 pounds) but on its native planet it weighs only 400 pounds. A deep chest houses a large heart and voluminous lungs for extracting oxygen from the relatively thinner atmosphere of their planet.

Bipedalism would be far commoner for large animals on a lower-gravity planet than it is on Earth. The two limbs available for support would be under less stress so they would not have to be as precisely engineered or as strong. Unlike a kangaroo, the only large mammal on Earth besides Man that is a biped, these green antelopes are striders, not hoppers. Their short tails are the clue: Large hoppers always need a long tail for a counterweight, but striders can operate with or without such apparatus.

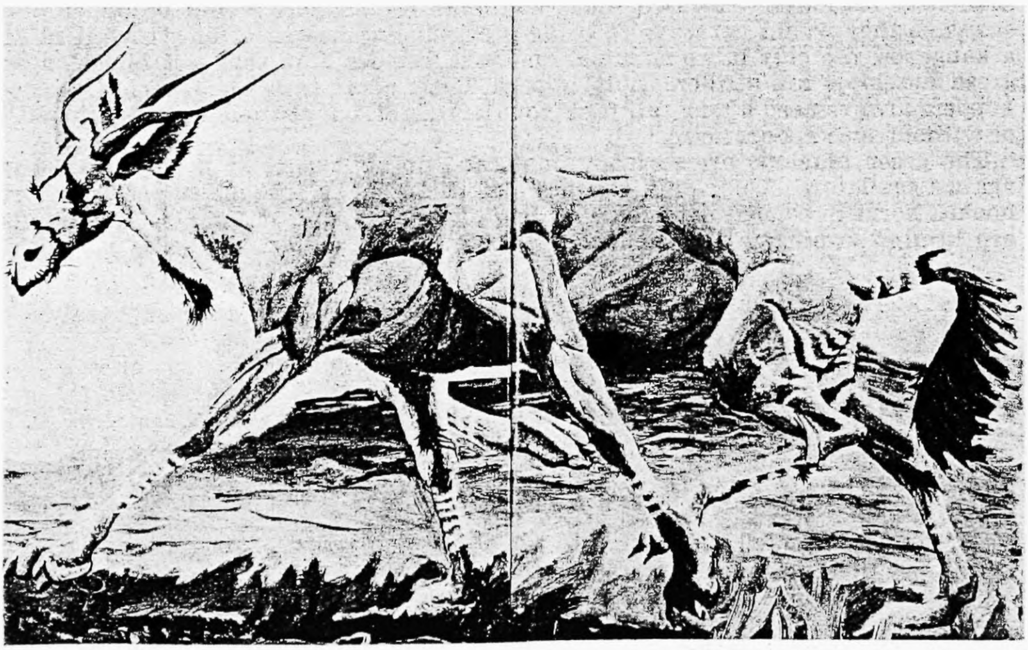
The green antelope are social animals and do not use their horns in defense against predators: Their only effective defense is flight. The males use the short hooked horns in combat over females. Such fights are violent, but few individuals are injured owning to the ineffective positioning of the hooks on the horns.

THE ADVANTAGE OF SIX-LEGGEDNESS



These two green antelope are from a planet with a temperate climate and low gravity, which allows such large animals to get around with only two legs. The green is camouflage to avoid their predators.

The hexalope inhabits a hot, dry world with gravity like that on Earth. The lethal horns are used in defense against their enemies. Six-leggedness leads to stability and no more confusion than in insects.



The hexalope is a six-legged herbivore that evolved on a planet with a very dry climate and gravity similar to Earth's. Because there is so little water on the planet, the fishlike predecessors of land animals were bottom crawlers in shallow, often seasonal seas and lakes, rather than being open-ocean swimmers as were the first fish of Earth. Early marine organisms on Earth had multiple pairs of fins but lost them when they became true swimmers: For a free-swimming, torpedo-shaped object, two sets of diving planes are both necessary and sufficient. So when certain earthly fish began to move out of the sea onto land, the four fins became four legs. In contrast, on the hexalope's world, the original bottom-dwelling fish [illegible] were direct ancestors of the land-living forms and their terrestrial

There are advantages to having six legs. For example, hexapodal locomotion provides a support tripod for the animal even at fast gaits. (Four-legged animals have a stable tripod of limbs when walking but not at faster gaits.) An animal with a large central nervous system would not encounter any problems of co-ordinating its six legs, as one might at first think. After all, earthly insects with three pairs of legs are hardly noted for their well-developed mental powers but most of them walk just fine.

The hexalope is a social animal. Any combat that occurs between members of the species is highly ritualized. This is necessary because the long, multiple forked, backward-projecting horns are lethal. Highly evolved social animals rarely kill each other in combat: The primary use the animals have for their horns is self-defense against predators and both male and female hexalopes are so armed.

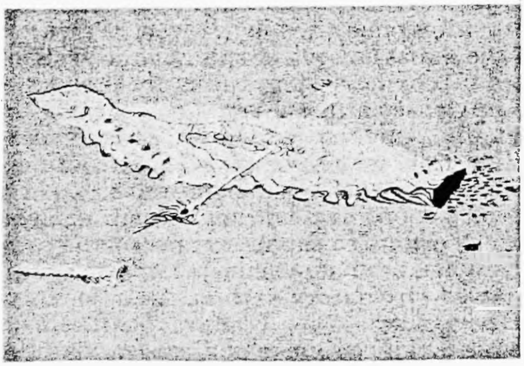
The striping of the head and tail is a kind of disruptive coloration which confuses a stalking predator as to the direction the hexalope will bolt if it is charged. The dark glandular patches on the legs are the sources of odors that are important in communication within a herd.

Once one gets over the idea that an antelopelike creature might have only two legs or might have six legs, there is nothing so surprising about these first two animals. Extraterrestrial animals should, one may think, be outlandish—but once one understands the conditions of their world and how these are most likely to affect evolution, nothing is really outlandish—and nothing is commonplace, either, unless you are the sort of person who could objectively consider a giraffe as a commonplace and predictable creature, have never heard of one before.

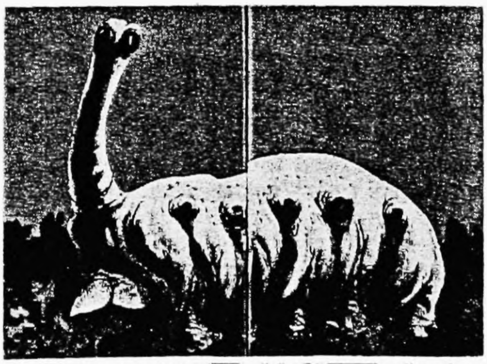
Suppose you had a planet with a generally low temperature and high gravity—three times that of Earth. This planet is engaged year-round in a perpetual ice age, with perhaps some water unfrozen on land near the equator in the summer. The difference in gravity would have little effect on the skeletal and locomotive systems of any marine form of life because the animal's density would be approximately that of the water in which it lives.

The outrigger ribbon fish is a filter-feeding fish from such a planet. Its large gills are used mainly for sieving small plankton from the water. Respiratory exchange of gases (that is, breathing) occurs through the animal's skin and fins. It's mouth is surrounded by a row of chemically and tactilely sensitive tentacles used to locate food organisms, and its long outriggers are also sensitive to the touch of such small animals. If the ribbon fish swims by a cloud of prey, the long outriggers may brush against the outer organisms in the cloud and the fish then turns and swims into its prey, mouth agape.

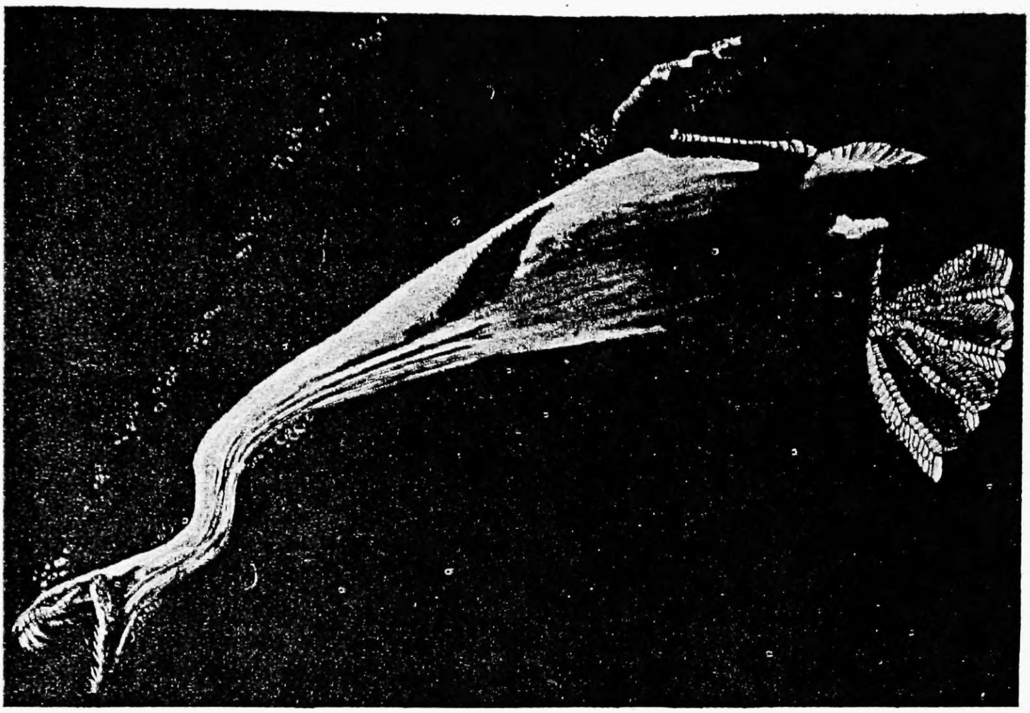
The ribbon fish's six eyes are rudimentary and primarily sensitive to difference in dark and light. A shadow falling on its eyes stimulates the fish to dive toward the relative safety of the bottom.



Outrigger ribbon fish filters plankton through gills from cold seas. Armlike projections are sensitive to the touch of its prey



Bandersnatch is an unfastidious herbivore. It sees and smells with the stalk; its mouth is found at the front of its body.



Sharing bandersnatch's high-gravity world is a huge diving reptile, plesiornis, that paddles with hind legs.

Inspired by Larry Niven's science-fiction novel, *World of Ptaavs*, the bandersnatch may satisfy any cravings for the thoroughly exotic. Its mass is equivalent to that of a 10,000-pound Earth animal such as a large elephant, but on its temperate, high-gravity planet, the bandersnatch weighs 30,000 pounds. For support, the animal is multilegged but, due to its great weight, relatively slow. A "salad-type" herbivore, it will eat any plant it comes across in its stately peregrinations, rather than searching out specific tasty or highly nutritious items.

Its large mouth is equipped with prehensile, petal-shaped lips and is located on the front of its body. The grinding apparatus consists of a series of vertical tooth-bearing bars. The large projection in front is a sensory stalk and bears organs of sight and smell, as well as serving as a primary integrating center for sensory stimuli. What we would think of as hearing is accomplished by a row of pressure-sensitive receptors that run the length of the animal's body, similar to the system seen in earthly fish and salamanders. Such a hearing system works for land animals on this high-gravity planet because its denser atmosphere is comparable to the density of water. As a hearing system, the bandersnatch's rows of receptors are well suited for ascertaining the direction from which sounds emanate but not as useful as an ear in detecting the changes in the quality of sound waves.

The bandersnatch breathes through a multiple-opening, tracheal breathing system. In its small ancestors, this system was adequate to supply oxygen to all body tissues, but in the larger animal, the system has been supplemented by lung sacs at the ends of the trachea as well as a closed circulatory system. As in earthly lungfish, the uptake of oxygen and the release of waste gas (carbon dioxide) are separated. In lungfish, oxygen is absorbed through the lungs and carbon dioxide is excreted through the gills. In the bandersnatch, gas absorption occurs via diffusion in the trachea; nitrogen and carbon dioxide are excreted through the skin, with little loss of water. The high humidity of the planet also reduces the problem of dehydration. Each of the five body segments has a separate tracheal segment and the exhalations are timed so that the net effect of all of this plumbing is to give the animal the appearance of continuously taking a long breath. It proceeds slowly through the landscape with a characteristic huffing sound.

While the bandersnatch placidly plies the landmasses of its planet, in the seas is the large diving reptile called the plesiornis. Its ancestors were short-tailed, four-legged land animals but, as has been the case on Earth, they returned to the

On Earth, most of the known marine reptiles evolved from terrestrial ancestors with long tails, and so most marine reptiles are tail-swimmers—crocodiles, ichthyosaurs, sea snakes. There are two other adaptations for swimming that a sea-returning land vertebrate starting off with four limbs may have. Fore-footed paddling is seen in seals, penguins and sea turtles, and hind-foot paddling is seen in sea lions and many diving birds. The plesiornis has a locomotive style unknown among earthly reptiles—it is a hind-foot paddler.

Differences in gravity and temperature directly affect the amount of oxygen dissolved in water, and the high atmospheric pressure on the planet of the plesiornis and the bandersnatch gives the big diving reptile a distinct advantage over an earthly diver of the same size. Each breath will have ten times the oxygen content as on Earth, so the animal can stay under for much longer dives without any elaborate breathing equipment. Of course, owing to the buoying effect of water, there is no more work involved in diving on the heavy-gravity planet than there would be on Earth; no more energy is required.

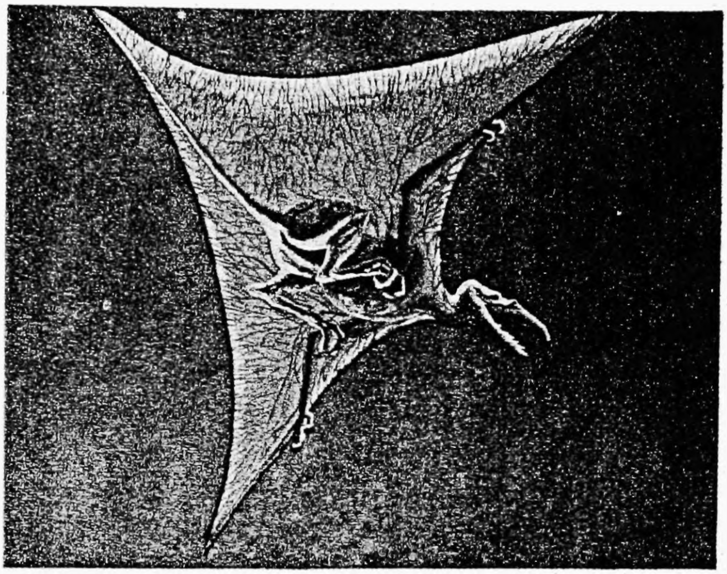
Humankind evolved as land animals, but human children and some adults continually dream of being able to fly. And even though some humans evolved into engineers and inventors who have permitted us to take a certain kind of flying for granted, the capacity to spread one's limbs and take to the air by oneself still eludes human grasp. If flying through the Earth's atmosphere at will remains a mysterious and wonderful dream (perhaps the ultimate explanation for the existence of bird watchers and butterfly collectors), then what would it be like to fly on another planet? What kind of creatures would have accomplished it?

The flying animals such as the three pictured . . . were the greatest challenge for me. Frankly, I didn't know much about flight when I started the project and, although I know more now, I still don't know as much as I'd like to.

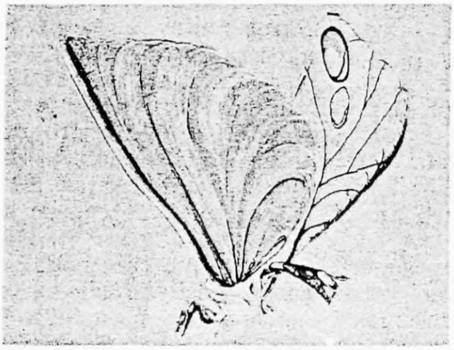
One thing I learned is that flying animals have to be very well engineered or they don't fly: It takes ten times as much energy to fly somewhere as to walk there (unless a change of altitude is involved in the walking route). In addition, it takes more power to fly slowly or rapidly than it takes to fly at some intermediate cruising speed. The factor that places an upper size limit on earthly fliers is not that of the strength of the materials available to build wings from, but the ability of their muscles to generate enough power to get off the ground. An albatross can generate enough power in its wing muscles to take off into the wind if the wind has a ground speed of 20 miles per hour, but it cannot take off in still air. The minimum speed at which an animal or airplane can fly is referred to as the stall speed.

For high-gravity planets I assume an atmospheric pressure ten times that of Earth's at sea level, even though they had only three times the Earth's gravity. This assumption is not unwarranted. The amount of atmosphere a planet has is relatively independent of the mass of its rocky core. If this assumption isn't made, the flying animals that are possible are also small and uninteresting. The much denser atmosphere combined with a slightly greater gravitational attraction improves the lift force of any particular type of wing. This means that, despite their greater weight, relatively large animals could fly on the high-gravity planets. In essence the denser atmosphere reduces the stall speed of the animals. The greater force of the winds on a high-gravity planet also facilitates flight in large animals.

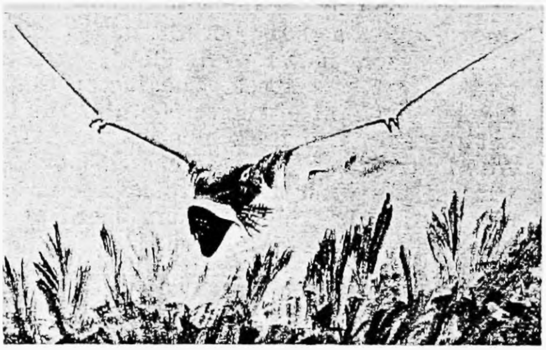
The great filter bat has an unusual ecological niche. It lives on a tropical, high-gravity planet and it is an aerial filter feeder. The large oval mouth has a specialized series of slits and featherlike filters at the corners. As the "bat" sweeps and glides above the dense tropical vegetation, a continuous flow of insect-bearing air passes into its mouth and out through the filters. The insects, against their best interests, remain in the filters to be lapped away by periodic sweep of the bat's tongue. The animal has poorly developed eyes but a well-developed sonar system. The large humps covering the wing muscle also house the sonar receptors. In the dense, turbid atmosphere of its home world, sonar is more useful than vision. Not only is light transmission reduced and distorted by the dense atmosphere, but the speed of sound is greater because of the increased pressure. The filter bat has a wingspan of 50 feet and a weight of 150 pounds on its native world.



Red hop-flier weighs eight pounds on its low-gravity planet. It achieves take-off by using strong hind legs and, just as a grasshopper's, its flights are short.



Gaudy pattern of butterfly lizard's two-foot wing span attracts males and warns predators that it is poisonous. It leaps well in a low-gravity world.



Great filter bat weighs 150 pounds and glides over vegetation, sieving insects from air. The dense atmosphere of high-gravity world permits it to fly.

The red hop-filter is a flying animal from a low-gravity world with a dry, desertlike climate. The thin air of its small world poses two major adaptive challenges. Firstly, a flying animal unprotected by shade dries out more easily than an animal hiding in the underbrush. Secondly, the thin air requires both large wing area and a relatively great stall speed. The lower gravity only par-

tially compensates for the thinner air. The hop-flier attains its initial takeoff velocity by using its powerful hind legs and, as with an Earth grasshopper, its flights are not very long. The wing membranes are well supplied with blood vessels and serve as a radiative surface for the body heat generated during flight. The scaled reptilian skin is ideally adapted to resist dehydration.

The animal is an active predator; on its home planet it weighs about eight pounds.

The butterfly lizard is an 11-inch-long flying reptile from a temperate, low-gravity planet. It has a two-foot wingspan and feeds upon insects and small vertebrates which it stalks and catches on the ground as well as in the air. The gaudy wings serve as a recognition signal during the breeding season and also as a warning to predators that the animal is poisonous. Similar bright warning colors are seen on distasteful or poisonous Earth animals. The wings are supported by a cartilagenous skeleton of greatly modified dermal scales. The flight musculature is located entirely on the shoulders and ribs. In contrast to the condition found in butterflies, the lizard's wings are composed of living tissue. They have an active blood supply and can be repaired if torn. The low gravity of the planet combined with well-developed legs enables the beast to be a relatively good leaper.

The great filter bat, the red hop-flier and the butterfly lizard hardly exhaust the potentialities for flight adaptations on low- and high-gravity planets. Think for a minute about the great red sac on the male frigate bird's throat, which he can inflate at will during the breeding season. It has nothing to do with his ability to fly but it certainly reminds one of a balloon. And having thought of balloons, think of other lighter-than-air craft, such as dirigibles. Could evolution have produced such a flight mechanism naturally Why not?

I designed an airship beast a herbivore from a planet with cold winters and heavy gravity, the same world as that of the ribbon fish. The airship beast weighs 200 pounds and it flies only twice a year when it migrates from the summer pasture of one hemisphere to the summer pastures of the other hemisphere. A few weeks before migrating, the animal begins to fill its airbag with hydrogen produced as a metabolic byproduct of the breakdown of sugar.

Much of the success of its aerial travel is due to the powerful winds of its high-gravity planet, but airship beasts are prone to many dangers during their migration : Thunder and lightning storms are common on high-gravity worlds and they risk ignition of the hydrogen as with the *Hindenburg;* aerial predators attempt to tear the gas bag in order to bring their prey down to earth (as it were) ; and, in addition, they may be blown off course. With such hazards, and with their relatively feeble wings and low food stores, many never reach the summer feeding grounds. However, the large food supply available to them as migratory herbivores gives them a great reproductive potential and the species survives despite the terrific mortality among its individual members.

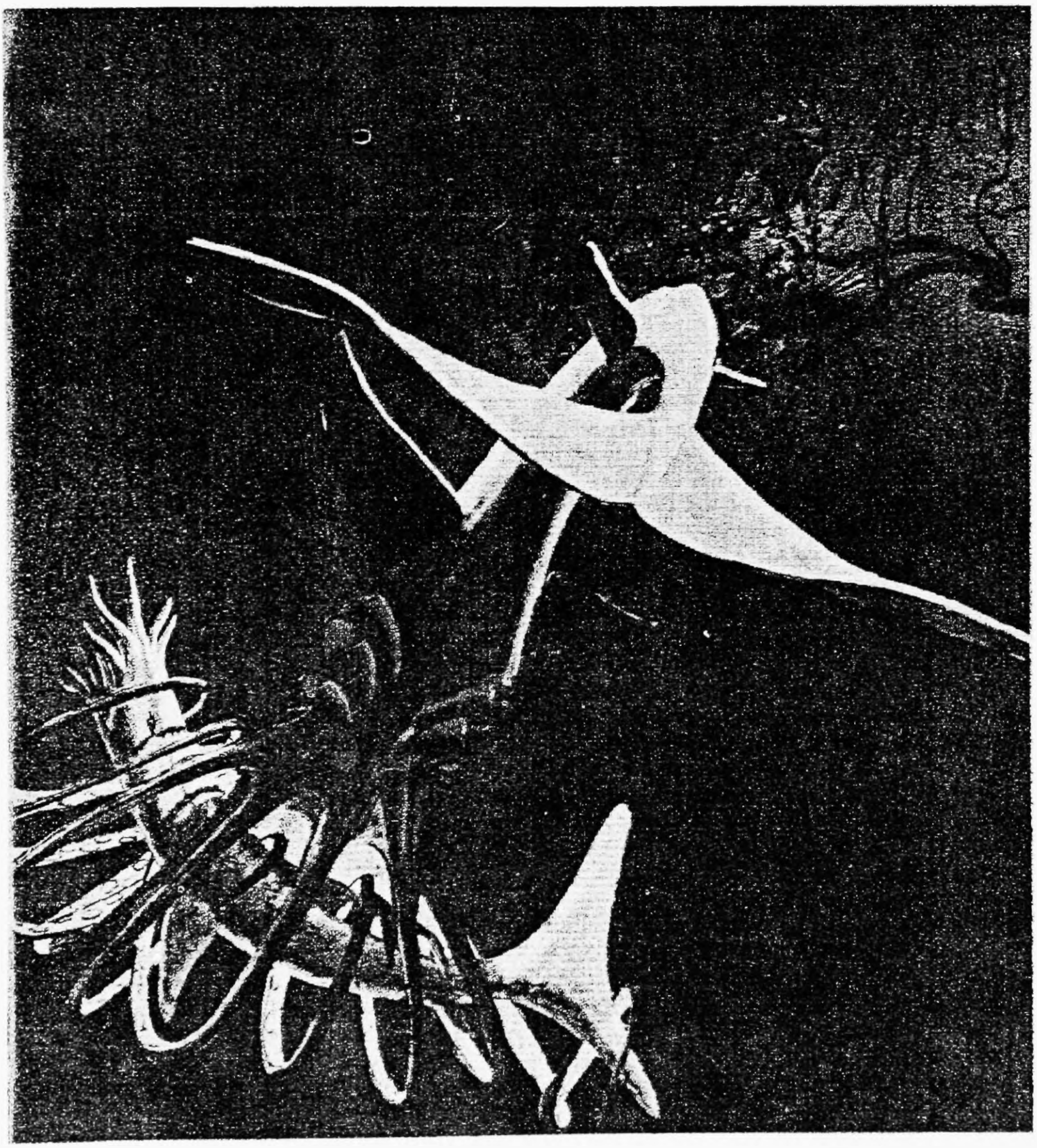
Finally, the squish or shark-squid is a predacious marine organism from the temperate, low-gravity world, also inhabited by the butterfly lizard. It is a true aquatic form, not the descendent of terrestrial animals which reentered the sea. The large gills are an adaptation to the low level of oxygen in the waters it inhabits. Not only does its planet's thin atmoshere reduce the amount of oxygen that the water will contain, but warm waters also hold relatively less oxygen than do colder waters.

The squish uses a dual mode of locomotion : the forward facing gill clefts are also the intake ports for a jet propulsion system used in extremely rapid travel. The water, under pressure, is pumped backward through the gills and then out an exit slit (hidden by the tail fin in the picture). A small amount of this high-pressure water is diverted to maintain the rigidity of the tentacles during the jet spurt. The tentacles can be stiffened by this hydraulic skeleton so that they form a compact streamlined cone. During slow swimming or when the tentacles are in use the animal propels itself by strokes of its tail. The temperate oceans in which the squish lives have many levels of predators and a complex food net. The squish is a predator on large fish, not a filter feeder.

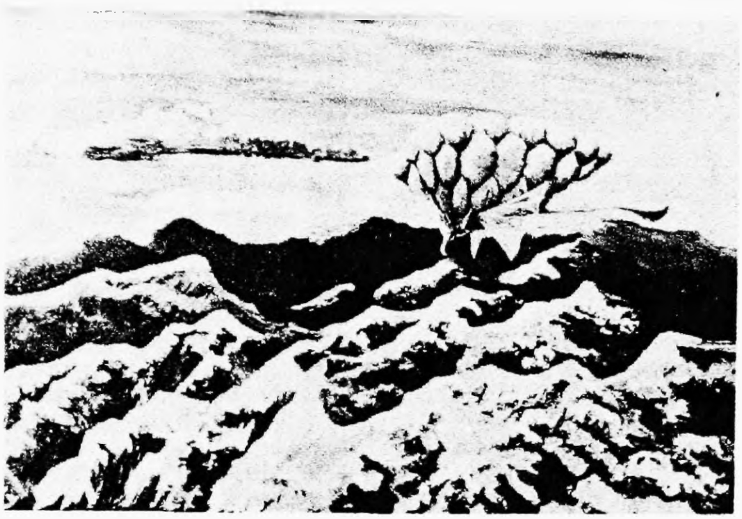
These, then, are some animals for an interstellar zoo. Though they almost certainly don't exist anywhere in the universe, they *could*—under the right circumstances. Anyway, I am rather fond of them because they are mine. There are 17 others in the exhibit including the toad face, a birdlike flying insect ; the Cthulu "larva," a bottom dwelling, largely motionless vertebrate, the main characteristic of which is that it is disgusting ; the 90-foot long, hermaphroditic basil-

ocetus, which lives alone in frigid seas; the similarly solitary legadillo, a huge, armored, multilegged herbivore that feeds on desert plants on a high-gravity planet; the nocturnal owl cat that is noteworthy for its feathery fur; a centaur-like creature, one of the few intelligent animals in the exhibit, which evolved as did the hexalope from multilegged marine ancestors; and the two-headed, three-legged puppeteer, whose hind foot is a powerful weapon if a bit of an embarrassment in locomotion.

Of course, there are many more variables one could use and so many more types of planets and, therefore, of animals. But until we get to other planets, it is fun to speculate about what life forms we might find out there. It is a game anyone can play and it is not just a harmless pastime. Such speculation can perhaps help us better understand how the Earth's environment has shaped the creatures that dwell upon it, including us.



The shark-squid, a highly efficient marine predator, can swim with its tail or, for short, fast bursts, by hydraulic pumping of water through its large gills.



The herbivorous airship beast inflates itself
with hydrogen and is blown by strong winds in
dangerous migrations on a high-gravity planet.

APPENDIX E

Selected Bibliography

Allen, Thomas B. The Quest: a report on extraterrestrial life. Philadelphia, Chilton Books, 1965. 250 p.

Berendzen, Richard. Search for life in the universe. Vital issues, v. 22, June 1975.

———, ed. Life beyond Earth and the mind of man; a symposium held at Boston University on November 20, 1972. Washington, D.C., National Aeronautics and Space Administration, 1973. 106 p.

Bracewell, Ronald N. Opening message from an extraterrestrial probe. Astronautics and aeronautics, v. 11, May 1973: 58–60.

———. The galactic club. Stanford, California, Stanford Alumni Association, 1974.

Bradbury, Ray, et. al. Mars and the mind of man. New York, Harper & Row, 1973.

Cameron, A. G. W. Interstellar communication: a collection of reprints and original contributions. New York, W. A. Benjamin, 1963. 317 p.

Copland, Alexander. Existence of other worlds: peopled with living and intelligent beings. London, J. G. & F. Rivington, 1834. 210 p.

Cruikshank, Dale P. and David Morrison. Galilean satellites of Jupiter. Scientific American, May 1976, v. 234: 108–116.

Dole, Stephen. Habitable planets for man. Santa Monica, California, the RAND Corporation, March 1964. 135 p.

Drake, Frank D. Intelligent life in space. New York, Macmillan, 1962. 111 p.

———. On hands and knees in search of elysium. Technology review, v. 78, June 1976: 22–29.

du Fontenelle, Bernard. Plurality of Worlds. London, Red Lyon in Pater-noster-row, 1728. 200 p.

Firsoff, V.A. Life among the stars. London, Allan Wingate, 1974. 196 p.

Foster, G. V. Non-human artifacts in the solar system. Spaceflight, v. 14, Dec. 1972: 447–453.

Folk, G. Edgar Jr. Textbook of environmental physiology. Philadelphia, Lea and Febiger, 2nd ed., 1974. 394 p.

Gatewood, George. On the astrometric detection of neighboring planetary systems. Icarus, v. 27, Jan. 1976: 1–12.

Hoyle, Fred. The black cloud. New York, Signet books, 1959. 190 p.

Kuiper, T. B. H. and M. Morris. Searching for extraterrestrial civilizations. Science, v. 196, May 6, 1977: 616–621.

Lear, John. Search for man's relatives among the stars. Saturday review, v. LV, June 10, 1972: 32–37.

MacGowan, Roger A. and Frederick I. Ordway III. Intelligence in the universe. New Jersey, Prentice-Hall, 1966. 377 p.

Mallove, Eugene and Robert L. Forward. Bibliography of interstellar travel and communication. Journal of the British interplanetary society, v. 27, pp. 921–943; v. 28, pp. 191–219; v. 29, pp. 494–517.

Michaud, Michael A. G. Interstellar negotiation. Foreign service journal, v. 49, Dec. 1972: 10–14.

National Aeronautics and Space Administration. Viking 1: Early Results. NASA SP 408. Washington, D.C., NASA 1976, 63 p.

Oja, Heikki. New starts to the planets. Spaceflight, v. 17, June 1975: 215–218.

Oliver, Bernard M. Search for extraterrestrial intelligence. Engineering and science, v. XXXVIII, Dec. 1974–Jan. 1975: 7–11, 30–32.

Ordway, Frederick I. Life in other solar systems. New York, E. P. Dutton, 1965. 94 p.

Ponnamperuma, Cyril and A. G. W. Cameron. Interstellar communication: scientific perspectives. Boston, Houghton Mifflin, 1974. 186 p.

Powell, Conley. Interstellar flight and intelligence in the universe. Spaceflight, v. 14, Dec. 1972: 442–447.

Prehoda, Robert W. Suspended animation: the research possibility that may allow man to conquer the limiting chains of time. Philadelphia, Chilton Books, 1969. 191 p.

Project Cyclops: a design study of a system for detecting extraterrestrial intelligent life. Moffett Field, California, NASA, rev. ed. July 1973. 172 p.

Ridpath, Ian. An ear to the void. New scientist, May 12, 1977: 326–328.

Sagan, Carl. Communication with extraterrestrial intelligence. Cambridge, Mass., Massachusetts Institute of Technology, 1972. 356 p.

———. Cosmic connection. New York, Anchor Press, 1973. 267 p.

Sagan, Carl and Frank Drake. Search for extraterrestrial intelligence. Scientific American, v. 232, May 1975: 80–89.

Sheaffer, Robert. 1977 SETI progress report. Spaceflight, v. 19, Sept. 1977: 307–310.

Shklovskii, I. S. Possible uniqueness of rational life in the universe. NASA Technical Translation of "O vozmozhnoy unikal'nosti razumnoy zhizni vo Vselennoy," Voprosy filosofii, No. 9, 1976, pp. 80–93. Washington, D.C., National Aeronautics and Space Administration, Feb. 1977. NASA TT F–17, 404.

Shklovskii, I. S. and Carl Sagan. Intelligent life in the universe. San Francisco, Holden-day, 1966. 488 p.

Smith, Marcia. Extraterrestrial intelligence and unidentified flying objects: a selected, annotated bibliography. Washington, D.C., Library of Congress, Congressional Research Service, Feb. 18, 1976. Number 76–35 SP. 45 p.

Sobel, Dave. Arecibo radio telescope. Space world, v. J–11, Dec. 1973: 23–24.

Soffen, Gerald A. Scientific results of the Viking mission. Science, v. 194, Dec. 17, 1976: 1274 ff.

Solar system. Scientific American, v. 233, Sept. 1975. entire issue.

Sullivan, Walter. We are not alone. New York, McGraw-Hill, 1964. 291 p.

U.S. National Committee for the International Institute of Refrigeration. Round table conference on the cryogenic preservation of cell cultures. Washington, D.C., National Academy of Sciences, 1975. 78 p.

Wells, Ernest H. Search for life in space. Murfreesboro, Tennessee, DeHoff publications, 1975. 106 p.

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