The Search for Extraterrestrial Intelligence

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During the last four decades a quiet revolution has swept through the scientific community. Scientists who only a quarter of a century ago would have rejected the idea that the universe may be filled with intelligent life have come to accept this belief. Indeed, many now feel that it may be man's destiny—you might say his first step toward maturity—to contact that life, to learn about it, and to share in its goals.

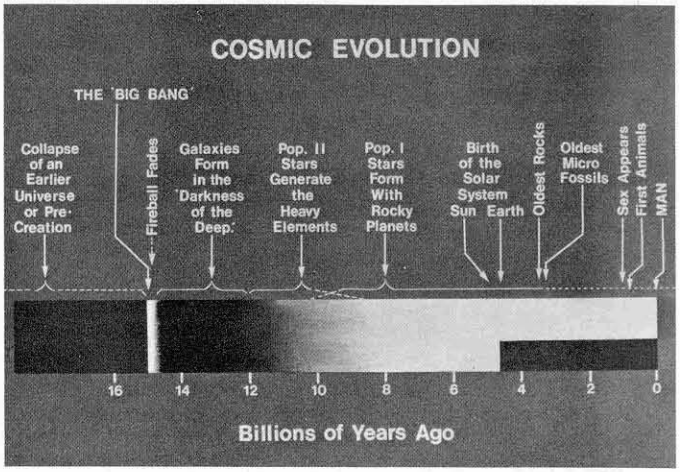
This change in belief is a result of many discoveries in many different fields—in astronomy, in nuclear physics, in atmospheric chemistry, in geophysics, paleontology, biology, and others—and many of these discoveries have been made at Caltech. Out of all of these discoveries has emerged a new and grander picture of the world, one that may ultimately reshape man's entire philosophy. The picture we now behold is one of *cosmic evolution*: a universe that was born and that has evolved into galaxies of stars and finally into living things. It is a universe that will continue to evolve for aeons to come before it either vanishes into oblivion, collapses toward rebirth, or comes to some end that we cannot yet foresee.

The universe as we see it today is expanding. The galaxies of stars are flying apart at a speed proportional to distance (that is, the farther apart they are, the faster they are receding from each other). This expansion suggests an explosive beginning, and indeed if we run the film backward through the projector and apply the known laws of classical and nuclear physics, we can reconstruct what things must have been like about 15 billion years ago when it all began.

We see the universe beginning as an awesome fireball, inconceivably hot and dense. The theories of nuclear physics suggest that only *one second* after the very instant of birth, all the particle annihilation had stopped, the hadron era was over, the lepton era was over, and all of the primordial matter of the universe (only hydrogen and helium) was left as a sort of a faint precipitate in this very early inferno of the fireball.

The "interior" of that fireball was and is the whole universe as we know it. We are inside the expanded fireball, and so far as we are concerned, there is no outside. In a sense, we may consider the universe to be an immense black hole.

For the next million years or so, as the expansion continued, the primordial matter was trapped by the intense blaze of radiation, and could not condense. One



In 15 billion years the universe has evolved from the blazing inferno of the primordial fireball into galaxies of stars surrounded by planets, many of which may support intelligent life. Out of chaos the wonderful laws of nuclear physics and chemistry have produced the complexity of the brain. Only the expansion of the universe prevents this evolution from being a violation of the second law of thermodynamics.

million years after birth, the universe was a pure blaze of light, as bright as the surface of the sun.

By the end of another 100 million years the continuing expansion had cooled the radiation to the point where all the light had disappeared. The entire universe was then about at room temperature, and the matter was of nearly uniform density everywhere. Imagine all space filled with gas at about room temperature, and no light anywhere. The hydrogen and helium were now free to begin their contraction into huge clouds that were to become galaxies of stars. But as yet there were no stars, and "Darkness was everywhere on the face of the deep."

Then each galactic gas cloud fragmented into billions of globules, each of which contracted until the heat generated in their centers kindled the fires of hydrogen fusion. Once again there was light—no longer a blaze of light in all directions, but billions of pinpoints of light: the early stars. Since these early stars were formed only out of hydrogen and helium, the only matter left over from the original fireball, none of them had rocky earth-like planets around them. They may have had planets, but they were gaseous ones. Calcium, aluminum, silicon, oxygen—none of these elements existed yet.

Stars, then and now, are the furnaces in which all the chemical elements heavier than helium seem to have been formed. Stars spend most of their lives on what is known as the main sequence, quietly burning hydrogen into helium in order to supply the light and heat that they radiate into space. During this phase, the luminosity, or total power output, of a star is proportional to the 3.5 power of the star's mass. The result is that although massive stars have a lot more fuel to burn, they squander it at a prodigious rate and live only a few million years, while very small stars, which may have very little fuel, burn it so slowly that they live for tens or hundreds of billions of years. (No star much smaller than our sun has yet left the main sequence.) When the hydrogen in the core of the star is exhausted, the star blows up into a red giant. Then helium burning begins in the core, and the production of heavier elements commences.

In their red-giant phase, stars go through very complex cycles that are not fully understood yet. But we do know that when a massive star—one that's several times more massive than our sun—completes its fusion stages, it does not shrink to become a white dwarf as our sun will do some seven billion years from today; instead, it ends its life as a supernova.

For a few weeks after this huge explosion, these massive stars shine with such supernal brilliance that they outshine the whole galaxy and can be seen in the daytime sky. These events happen only once or twice a century in a single galaxy, but there have been many recorded instances of supernovae appearing both in our galaxy and in nearby ones. The Chinese observed such a star in our galaxy in the year 1054 A.D.; they called it a "guest" star. It appeared from nowhere and was visible in the daytime sky. It's very interesting to note that no record of the appearance of this star exists in Western Europe, where church dogma at the time declared the heavens to be eternal and unchanging. Apparently it was far easier not to see this brilliant object than to have one's fingernails pulled out by the roots for heresy. Now, 920 years later, we know the object as the Crab Nebula, and it's the subject of much interesting research today.

Most of the matter of this star is seen flying out into space, there to enrich the interstellar medium with the heavy elements that were formed by nuclear fusion, neutron capture, and beta decay. Someday, somewhere, out of this enriched gas and dust a new good earth may be born. The calcium in our very bones came from similar explosions billions of years ago. We are quite literally little bits of stardust.

Apparently, in the very early stages of the Galaxy—the first few billion years—hundreds of generations of short-lived massive stars exploded as supernovae. After billions of these had flashed throughout the Galaxy, enough heavy elements were added to permit Population I stars to form.* These are the stars that can have rocky planets about them.

Stars are still being born even today in our own Milky Way and in other galaxies. The present theory is that the spiral arms of a galaxy are not regions of heavy star concentrations but rather that they are regions of high gas and dust concentration: the maternity wards of the galaxy where new stars are being born at a rapid rate. It's the very brilliant high-luminosity O and B** stars that don't live long enough to get very far from their birthplaces that give the arms their extra brightness. So the process of interstellar gas enrichment is still going on.

Our sun is a fairly young star. It's only five billion years old. Over 100 billion Population I stars in our galaxy are older than the sun. How many of these have earth-like planets and how many of these good earths support intelligent life? Before we try to answer that question, we should look briefly at what did happen on earth.

After the sun had condensed, leaving a disk of whirling, turbulent matter behind, this matter began to coalesce into planets. We find that the outer planets—Jupiter,

*In 1944, Walter Baade of the Mt. Wilson Observatory divided stars into groups according to their ages and habitats. Population I includes younger stars associated with gas and dust; for example, those found in galactic clusters or the spiral arms of galaxies. Population II stars are older and are found in regions essentially devoid of gas and dust.

**Almost all stars fall into one of seven spectral classes: O, B, A, F, G, K, or M. This system of classification, based on the relative intensity of selected absorption lines in the stellar spectra, furnishes a continuous sequence of spectra related to colors (blue through red) and therefore the stars' surface temperatures (45,000°F. through 2,400°F. or less). The types are further subdivided by numbers representing a tenth of a spectral class; for example, an F_5 star is halfway between an F- and a G-type star.

Saturn, Uranus, and Neptune—have about the same relative abundance of chemical elements as the sun. They are typical of the material out of which the sun condensed. If you were to strip Jupiter of its atmosphere, it would be only about 5 or 6 times heavier than Earth, whereas with its atmosphere it's about 318 times heavier. The outer planets are mostly hydrogen and helium, with only about 2 percent heavy elements. The inner planets, by contrast, are almost all heavy elements, with very little hydrogen and helium.

When the sun was young, the solar wind was a real gale. Apparently, the young sun blasted most of the hydrogen and helium out of the inner part of the solar nebula, leaving behind only the dust—or perhaps the already accreted planets. It is out of this dust that you and I were made.

Mercury, Venus, Mars, Earth, and the moon were probably formed without atmospheres and had to generate them from gases produced by volcanoes. This only happened to an appreciable extent on Earth and Venus. The moon and Mercury are too small to have had any appreciable amount of vulcanism. Mars is a borderline case. We can see extinct volcanoes there, and indeed Mars has some atmosphere, but only about 1 percent as much as Earth. Apparently the ratio of surface to volume in the smaller planets was great enough to radiate the internal heat fast enough to prevent a large amount of vulcanism. On Earth the steam from volcanoes condensed into seas. There has been enough vulcanism on Earth to account for all the seas and many times the amount of atmosphere that we have today.

The primitive atmosphere was thus composed of volcanic gases, gases like methane, ammonia, hydrogen sulphide, carbon dioxide, and sulphur dioxide. A great turning point in scientific belief came when Stanley Miller (professor of chemistry at the University of California) demonstrated that a mixture of such gases, when exposed to ultraviolet light, produces amino acids, simple sugars, porphyrins, and other compounds that are the building blocks of proteins and of DNA. Apparently the atmospheric chemistry was such as to *fertilize* the early earth.

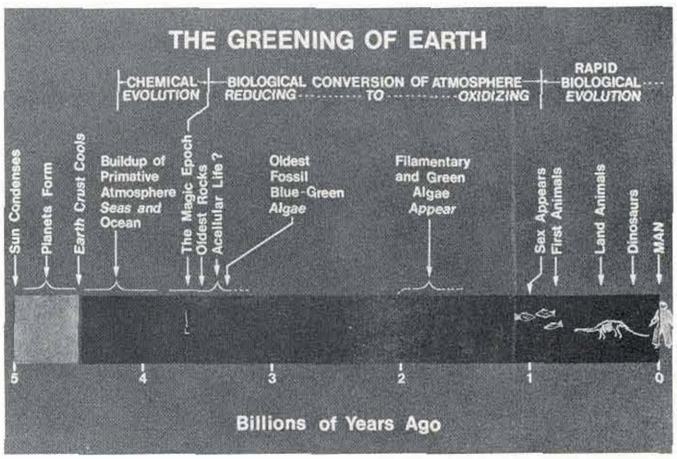
Some of these organic compounds have also been detected in the interstellar medium by radio astronomers, so we know that they are not peculiar to the surfaces of planets. Nevertheless they probably were produced on Earth in very great amounts, perhaps several pounds for each square inch of Earth's surface. They fell out of the early atmosphere into the early seas, turning these seas into a consommé or chicken soup. Literally. It was out of this broth that life began.

We don't know when or how the first self-replicating molecules formed. We don't know how the first DNA began. We don't know, either, when the first cell was formed to isolate that DNA in an environment of its own making. These things remain to be discovered. But we do know that on a cosmic time scale it didn't take very long. Deep in some of the oldest sedimentary deposits on Earth microfossil remains of blue-green algae have been discovered that date back 3.35 billion years. Considering that blue-green algae was certainly not the first self-replicating organism formed, that it must have been preceded by simpler forms of life—perhaps bare nuclei—and that a long period of evolution must have taken place to produce as complicated a thing as the blue-green algae, it's quite evident that life on Earth began almost as soon as atmospheric evolution had rendered it fertile.

Now we come to quite an epoch. The primitive atmosphere was a reducing atmosphere, full of noxious gases that would kill all animal life. What seems to have happened is that for about two and a half billion years the blue-green algae and its descendants patiently removed the carbon dioxide and released oxygen. All during this time the volcanoes were still pouring more carbon dioxide into the atmosphere, and the algae thrived on it. Most of Earth's carbon that was once in this carbon dioxide is now locked away in limestone produced in the early oceans.

On Venus, the temperature was just high enough that seas did not form and life did not begin. The volcanoes continued to belch forth carbon dioxide, which began to trap the sun's heat. We now know from our space program that the surface of Venus is hot enough to melt lead. It suffocates under a blanket of carbon dioxide about a hundred times heavier than Earth's atmosphere. Blue-green algae saved Earth from this fate.

Less than a billion years ago a major advance occurred in the stream of life. Life invented sex. This is of



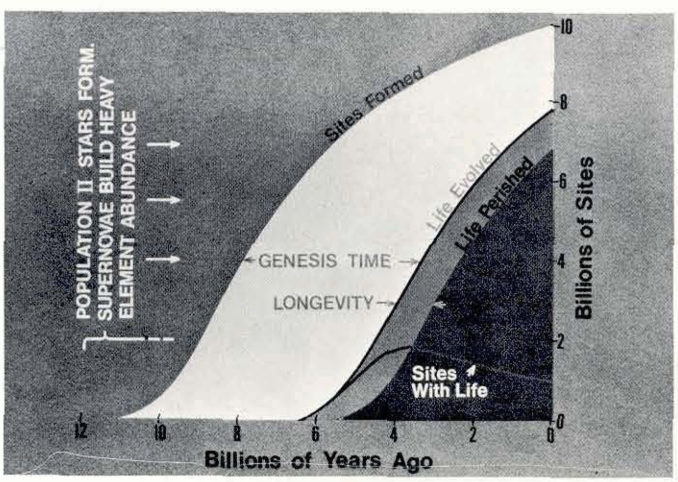
Three and a half billion years of vulcanism, chemical evolution, and atmospheric evolution produced the green hills of Earth and set the stage for animal life. A similar development seems likely on any planet of earth-like composition, temperature, and size.

enormous genetic importance, because prior to the invention of sex a favorable mutation that occurred in one member of the species had to be succeeded by another favorable mutation in that same member or its descendants in order for the combination to occur in a single individual. With the advent of sex there was intermixing, and as a result, favorable mutations that had occurred in separate individuals of the species combined much more readily. (And that's really all you need to know about sex.)

The geological record shows that it was right after the invention of sex that evolution really took off. Marine animals appeared, followed by land plants, land animals, the reptiles, birds, and trees. Angiosperms (flowering plants) appeared. Their rich seeds changed the whole food balance of the world so that much more animal life was possible than ever before. Finally—very late in the scene—man appeared. All of this came about in the relatively short span of 800 million years.

What I find so impressive is that the steps from fireball to life, from chaos at the beginning to the indescribable complexity of, say, the human brain, all happened through natural law. Surely this must be the greatest miracle of all —that the universe, out of the fire in its beginning, has evolved not only into stars and planets, but into living things that now have eyes and minds that can contemplate the universe that begat them. What greater miracle does man need?

The crucial point to this story is that there doesn't seem to be anything in this whole pageant of evolution that is in any way peculiar to Earth. There is no special quality that Earth alone possesses, and if this is true, then the Copernican revolution is indeed complete.



Evolution of Life Sites—After supernovae explosions had enriched the interstellar gas with heavy elements, stars with rocky planets began to form. There are now on the order of ten billion life sites in our Galaxy. On some life has not yet evolved, on others it has perished. The number of advanced cultures at this time is roughly equal to the average longevity of advanced cultures in years; i.e., $N \approx L$.

Of course, not every star is a good sun, so we don't expect to find life around every star. To begin with, stars larger than F_5 stars have a total main-sequence lifetime that's less than the time it took life to evolve on Earth. Unless our evolution was unusually slow, there aren't evolved civilizations around such stars. Stars smaller than about K_5 have such a low light and heat output that a planet, to be warm enough, would have to be in such a tight orbit that the tidal coupling would stop its rotation. It's rather unlikely that on such a planet there would be benign enough conditions for life to evolve. So we think that only middle-class stars within the size range from about F_5 down to possibly K_5 can be good suns. Fortunately, there are a lot of these; about 20 to 25 percent of all the stars fall into this spectral class range.

But not every good sun will have a good earth around it. We think that almost all suns have planets, but in some systems the distribution of the planets may be wrong. There may be none at the right radius from the star to be at the proper temperature. Or the favorably situated planet may be too small to have volcanoes, so it just goes around forever and never generates life. Or it may have too much vulcanism, so that the entire planet is covered with ocean, in which case life could start, and might even evolve into intelligent counterparts of our Cetaciae (members of the order that includes aquatic mammals such as the dolphin and the whale). But it's doubtful they'd ever build radio telescopes in their marine environment.

When we take these factors into account, we conclude that out of the few hundred billion stars in the Galaxy, there are perhaps ten billion life sites. That is to say, there are about ten billion places where life has either evolved and perished, or exists now, or will someday evolve—sites that are destined to, or have already, fulfilled their task of supporting life. But if *we* want to contact any other life in the Galaxy, it must exist during this epoch, not billions of years in the past, or billions of years in the future. What can galactic evolution tells us about this?

Population I stars began to form about ten billion years ago. The rate was very rapid from about nine billion to about six billion years ago, but has slowed down since then, as the interstellar gas and dust has become somewhat depleted. Among the stars that developed during this early period were many F, G, and K stars with planets that were destined to support life. If our own genesis time is typical, then after about four or five billion years intelligent life evolved on a fair fraction of these sites, so there was probably intelligent life in the Milky Way before our sun was born. Unless the longevity of civilizations is typically billions of years, there were more of them in the past than there are now.

When one includes the best estimates for all the astronomical and biological selectivity factors, it turns out that

Man's first step toward maturity may be to contact life beyond the solar system

the number of intelligent races in this one Galaxy at the present time is about equal to the average number of years that such civilizations exist. The significance of this is pretty clear. It says that if civilizations usually solve their societal, ecological, population, and resource problems—and therefore live a billion or more years—then the Galaxy is teeming with intelligent life. If, on the other hand, they kill themselves off after only a hundred years in nuclear wars or some equally stupid way, then the Galaxy is practically devoid of intelligent life.

So the question of whether there is intelligent life out there depends, in the last analysis, upon how intelligent that life is. How can we find out? How can we be sure? How can we determine if other intelligent life indeed exists? For at least a decade it's been obvious that interstellar travel by spaceship is not only impractical for us at this time, but a virtual economic impossibility with any technology we can foresee. Chemical rockets are far too slow to do the job. It would take a chemically powered rocket about ten times as long as all recorded human history to get to the nearest star. It would be very difficult to recruit astronauts for that kind of a journey. If we could make the journey at something like seven-tenths the speed of light, then because of relativistic time-dilation, the flight time for the crew would be numerically equal to the distance in light years.

Let us consider the ultimate capabilities of nuclear space travel. Let's ignore any limitations imposed by modern technology and assume the best rocket permitted by natural law—one that annihilates matter with anti-matter. (Don't ask me how I'm going to build an anti-matter fuel tank. That's one of the problems I'm ignoring.) The pure radiation from the annihilation would constitute the rocket's exhaust.

Let's assume that we'll need about a thousand-ton payload in order to house a crew of ten for a decade. We'll need four stages, one to start the thing off, one to stop it when it gets there, one to start it back, and one to stop it when it gets home again. The relativisic rocket equations show that about 33,000 tons of matter and anti-matter would have to be annihilated to make a trip at seven-tenths the velocity of light. The total energy released would be enough to supply the entire present electrical power needs of the U.S. for half a million years. The takeoff power even from orbit would be about 10^{18} watts. This is ten times the solar power falling on the earth. But this wouldn't be sunlight. It would be hard gamma rays, and would present quite a shielding problem, especially for the ship itself. If only one part in a million of the rocket power leaked to the ship, the ship would have to get rid of a million megawatts of heat, and that requires a thousand square miles of radiating surface. That's hard to achieve with a total weight budget of a thousand tons.

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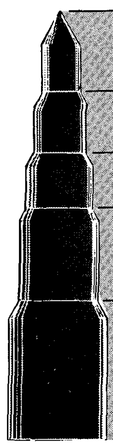
DESTINATION	BILLIONS OF MILES	LIGHT TIME	FLIGHT TIME
MARS	.15	13 MINUTES	~6 MONTHS
JUPITER	.50	45 MINUTES	~1.5 YEARS
PLUTO	3.5	5 HOURS	~10 YEARS
NEAREST STAR	25,000	4 YEARS	~40,000 YEARS

Interstellar Travel—Chemical rockets are far too slow (above) to take us to the stars or to let others visit us. Even ignoring technological limitations, relativistic nuclear rockets require prodigious energy expenditures (below).



	TONS	ENERGY IN YEARS OF U.S. ELECTRICAL CONSUMPTION
PAYLOAD	1000	
FOURTH STAGE	1400	51000
THIRD STAGE	3400	21000
SECOND STAGE	8200	123000
FIRST STAGE	20000	305000
TOTAL	34000	500000

The Search for Extraterrestrial Intelligence

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I think you can see why some of us feel that interstellar travel may never be accomplished economically. It's true that smaller, lighter-weight probes, and such things as interstellar ramjets (that no one knows how to build) have been proposed. But since over 10,000 stars might have to be sampled before we found the life we're seeking, then even with substantial reductions the costs are still prohibitive.

This is both a disappointment and a comfort. It's a disappointment because it would be very exciting to visit other worlds. But it's a comfort because *they* can't get *here*. I don't think we're ever going to end up as a gourmet delicacy on some alien's breakfast table.

It's my sincere belief that both UFO's and interstellar invasion are matters that we don't have to worry about. I feel the only practical approach to interstellar contact is to search for radiation transmitted by other civilizations either for their own purposes or in a deliberate attempt to communicate.

Three years ago I had the pleasure of conducting at the NASA Ames Research Center a summer study session called Project Cyclops. The goal was to assess whether present technology is up to the task of making a realistic search for this kind of radiation and what the cost might be in both money and time. I want to stress that this was a summer study that lasted three months, involved 20 people, and had a budget of $100,000—so I don't expect that the answers are definitive. But we did make some progress, and our major conclusions were these:

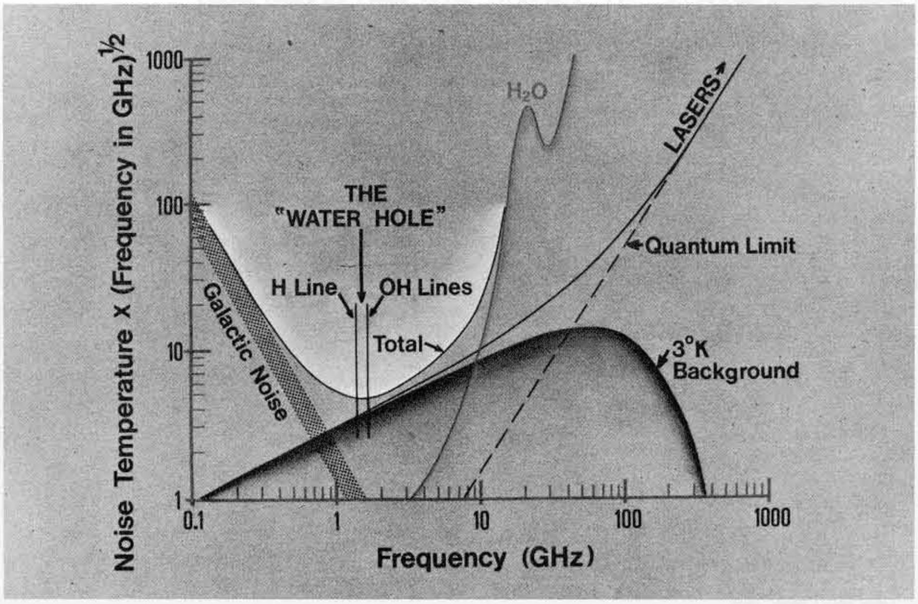
First, we feel very confident that the best region of the electromagnetic spectrum for the search—the place to tune our receivers—is in the microwave region, the wavelengths from 3 to about 30 centimeters. This is the quietest part of the spectrum; it has the least background noise associated with it. The narrower we make our receiver band, the less noise we'll admit and the weaker the detected signal can be. But there's a limit to how narrow we can make the bandwidth because, as a result of Doppler shifts, the signals are not absolutely steady in frequency. If the receiver is too narrow, the signal will drift clear through the passband before the receiver can respond. It turns out that the receiver bandwidth must be proportional to the square root of the operating frequency and, when this factor is included, the best part of the spectrum is from 1 to 2 gigahertz. One gigahertz (GHz) is a billion cycles per second. We'd like to narrow our window further so we wouldn't have to search so much of the spectrum, but we can't find any *technical* reasons to do so.

The Cyclops team felt that it found an appealing reason to favor a rather narrow region at the very optimum part of the spectrum. At 1.42 GHz there's a strong spectral line caused by interstellar hydrogen. Just a little bit higher in frequency, at 1.66 GHz, is another spectral line caused by hydroxyl ions in space. We think that this may be the interstellar communication band, defined for all of us by nature herself. Water separates into hydrogen and hydroxyl ions, both of which are important in all life processes. So is water.

Thus the band lying between the spectral lines of the two dissociation products of water is a poetically symbolic place for water-based life to search for its kind. Where shall we find other intelligent species? Why, at the age-old meeting place of all species—the waterhole.

The second conclusion of the Cyclops team was that it is now possible to build a receiver able to search the entire waterhole at one time instead of having slowly to tune a receiver through the billions of channels it contains and listen to each channel in sequence. In effect, this receiver is a kind of high-resolution spectroscope; it spreads out the waterhole into a very high dispersion spectrum and looks for a signal at each point in the spectrum simultaneously. In a thousand seconds it could spot any signal, even a drifting signal, if the received power were only one-billionth of the noise power in the waterhole band.

The third conclusion was that, even with this detector, and even using the best part of the spectrum, we are going to need a very large antenna system indeed, one perhaps several miles in diameter. Single, steerable antennas that big can't be built on Earth, and are probably prohibitively expensive to build in space. But what we can do is



The Waterhole—Frequency instabilities force us to wide receiver bandwidths the higher we go in frequency. This, together with the spectra of certain cosmic noise sources, makes the region from 1 to 2 gigahertz the ideal part of the entire electromagnetic spectrum. There we find the emission lines of the dissociation products of water standing like the Om and the Um on either side of what may be our gateway to the stars.

to plant an orchard of smaller antennas and add their outputs together. This is called a phased array.

With an array of a thousand or more antennas and with low-noise receivers, Cyclops could detect any signal in the waterhole in 1,000 seconds, if the flux from that signal was only five photons per second per square mile. We could eavesdrop on signals that might be radiated from planets out to a distance of about 100 light years, and we would be able to detect beacons of reasonable power from any of the million or more good suns within 1,000 light years.

The cost of this system is obviously large—on the order of $6 to $10 billion, depending on how big it has to be before we succeed. This expenditure might occur over a 10- or 20-year period as antennas were added to the array year after year. If we were to achieve contact soon, we would not need to build the full array. The rate of expenditure would be a little over half a billion dollars per year. That's less than Americans spend on cigarettes; it's almost in the noise level of the federal budget. Nevertheless, it's a lot of money, and to justify spending it, we have to expect some substantial benefits out of finding other intelligent life.

IS THERE INTELLIGENT LIFE ON EARTH ?

PROGRAM	$ BILLIONS PER YEAR	YEARS	POSSIBLE OUTCOME	
			WORST	BEST
NATIONAL DEFENSE	>200 (US ≈ 80)	?	CIVILIZATION ANNIHILATED	EFFORT IS WASTED
CYCLOPS	0.6	15	GREAT ADVANCES IN COSMOLOGY	SUPERHUMANITY BEGINS

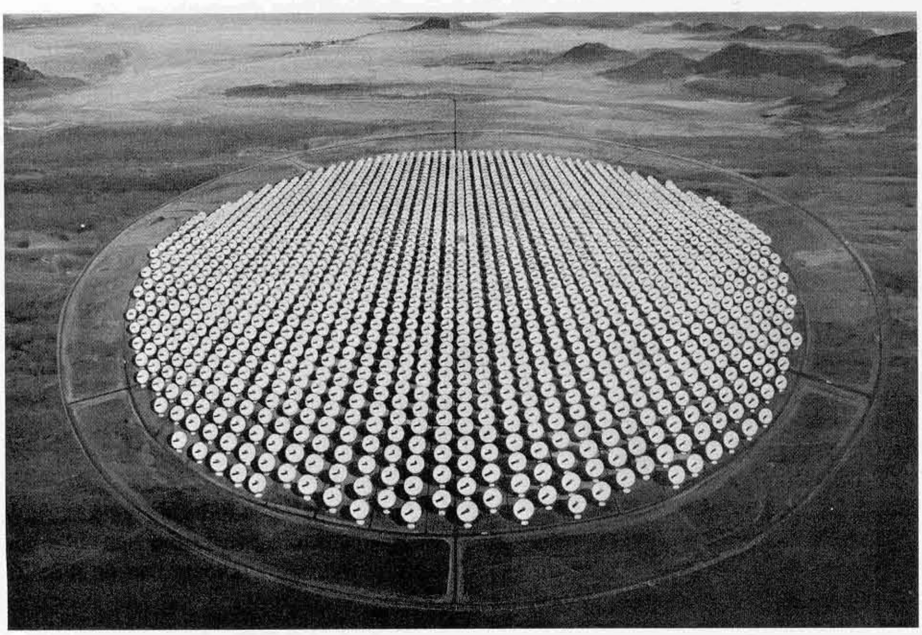
A Comparison of Two Societal Programs—The search for extraterrestrial intelligence is a gamble. So is national defense. We will never detect other civilizations unless we are mature enough ourselves to spend out of intellectual curiosity only a small part of what we now spend out of fear.

If our reasoning is correct, intelligent cultures have existed in the Galaxy for a few billion years, and if we find interstellar communication possible, they too certainly will have by now. Out of the billions of races that have attempted it, many must have been successful. Those that were successful probably have pooled their knowledge over the millennia and passed it on to younger races that joined their community. In fact, one of the requirements imposed on junior members might be to establish beacons to attract still younger races and thereby facilitate their first contact.

If all this is true, the task we face may be easier than we think. If this sort of a communicating community has been going on for this length of time, then a vast body of knowledge will have accumulated over the aeons, and this knowledge is accessible to any race whose technological prowess qualifies it.

I have termed this body of knowledge our galactic heritage, and I believe that access to it would truly be the most important event in the recorded history of man. The galactic heritage could include a large body of science that we have yet to discover—answers to questions that we haven't even thought of. It would include such things as pictures of the Galaxy taken several billion years ago by long-dead astronomers; it would include the natural histories of all the myriads of life forms that must exist in the planets of the member races. The whole story of cosmic evolution would be spread before us, illuminating not only the future but our past as well.

We might be able to tell if the expansion of the universe is going to slow down, and also whether the universe is going to recycle itself or not. We could see the unimaginably diverse kinds of life that evolution has produced in other worlds and learn their biochemistries, their variety of sense organs, and their psychologies. Culturally, we might learn new art forms and



Cyclops from the Air—The huge Cyclops array would be the most powerful radio telescope ever built and would permit real-time images of the radio sky. When the full power was not needed for any one task, the array could be subdivided to serve many astronomers simultaneously. Cyclops would be radio astronomy's Palomar.

aesthetic endeavors that would enrich our lives.

But more significant, I think, would be the societal benefits. We will be in touch with races that have achieved longevity. The galactic community would already have distilled out of its member cultures the political systems, the social forms, and the morality most conducive to survival, not for just a few generations, but for billions of years. We might learn how other races solved their pollution problems, their ecological problems, and how they have shouldered the responsibility for genetic evolution in a compassionate society.

If Cyclops could provide even a few of these answers, it seems to me that its cost would be justified. But finally, and perhaps even more important, participation in such a community would, in Neil Armstrong's words, "enhance the spirit of man." It would lift our horizons out of the sphere of our own rivalries, and involve us in the common cause of life throughout the Galaxy. What this cause may be, of course, no man can say. Perhaps someday life may save the whole universe from oblivion as life has already saved Earth from the heat death of Venus.

Since 1958, when NASA began, its total expenditure on all its space and aeronautical programs has been about $50 billion—about five times the estimated cost of Cyclops. Over this same 15-year period we have spent one *trillion* dollars out of fear—one thousand billion dollars to attack and to defend ourselves against attack by our fellow human beings.

I'd like you now to compare two programs: one the world is already engaged in, and one I would like to see started. The world spends over $200 billion per year on defense. Of this, we alone spend about $80 billion. How many years this will go on I don't know. The worst possible outcome of all this human effort would be Armageddon—doomsday for man. The best we can hope for is that our weapons will never be used.

The other program is Cyclops, which would take less than 1 percent as much money for only a few years. At the very least, the enormous capability of Cyclops as a radio telescope would extend our knowledge of the universe, probably to the cosmological horizon, back almost to the beginning of time. The *worst* outcome of Cyclops—failure in its primary mission—is far more exciting than the *best* outcome of our defense programs. The best outcome of Cyclops is something we cannot yet conceive. I can only suggest to you that childhood's end may await us at the waterhole. □

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